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SOME OBSERVATIONS ON THE RELATION OF LIGHT TO THE GROWTH OF DIATOMS.

BY GEORGE C. WHIPPLE.

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In a paper published in 1894, the writer suggested an explanation for the peculiar seasonal distribution of diatoms in lakes and ponds. It was shown that in deep ponds these minute plants are usually found abundantly during the spring and fall, but are almost entirely absent during the summer and winter; that these growths are closely connected with the phenomena of circulation and stagnation of the water, which phenomena are due to temperate changes; and that it is during the periods of the year when the water is in complete circulation throughout the vertical, that the diatom growths occur. The explanation offered for these facts had reference chiefly to the food supply. It was stated that diatoms require a sufficient supply of nitrogen in the form of nitrates, and that they require a free circulation of air; and it was shown how during the "periods of circulation" in the spring and fall these conditions were fulfilled. In the light of more extended observations and experiments this food supply theory, taken alone, is seen to be inadequate, and while it is true that the question of food is one of fundamental importance, yet there are other factors which materially influence their growth. With a view to determining the nature and effect of some of these influences, the writer has conducted during the past year several series of experiments, some of the results of which are here presented.

It is not an easy matter to cultivate diatoms successfully in the laboratory to obtain comparative results. They are organisms which have an extremely sensitive nature, and slight changes in their environment often make great differences in their growth. The temperature, the amount of light, the shape and size of the jar in which they are grown, the action of the glass upon the water, etc., are all disturbing elements affecting their growth. Take, for example, the shape of the jar. On one occasion three portions of a sample of Cochituate water were placed in three jars of various shapes, each of which held 500 cc. In the first, the water had a depth of 25 cm. and a surface area of 20 sq. cm.; in the second the depth was 7.1 cm. and the area 70 sq. cm.; in the third the depth was 2.7 cm. and the area 186 sq. cm. The three jars were placed side by side on the window sill, so that they received practically the same amount of light, and the temperature was found by observation to be the same in each case. The water in each jar originally contained 226 diatoms per cc. After standing ten days the water in the first jar contained 685 per cc.; in the second jar, 1,537; and in the third jar, 7,585. Of the last 6,060 were Synedra, 1,080 Melosira, 235 Tabellaria, 200 Asterionella, 10 Stephanodiscus.

The large number per cc. in the third jar was no doubt partly caused by greater evaporation from the large surface exposed and the consequent higher concentration of the organisms, but it was chiefly due to the greater opportunity for the absorption of air. In the deep jar the water could not take up the oxygen and carbonic acid from the air as fast as the diatoms used them up. Moreover the diatoms settled to the bottom of the jars, where they grew as a brown, velvety layer. The distance of these growths from the surface also affected their supply of air.

Another experiment made at the same time gave similar results. Into three cylinders, equal in diameter, were poured different quantities of the same sample of water. The first contained 100 cc., the second 200 cc., and the third 500 cc., the depths being, respectively, 1.4 cm., 2.9 cm., and 7.1 cm. The original water contained 226 diatoms per cc. After ten days the first jar contained 2,288, the second 1,733, and the third 1,537 per cc.

To more clearly illustrate the fact that diatoms do not grow without air, two cultures of reservoir water were made in flasks, one being open to the air and the other covered with a thin layer of oil. The

water originally contained 150 per cc. After twenty-five days the open flask contained 7,648 per cc., while the other contained but 192. An attempt to force a growth of diatoms in a flask by allowing air to continually bubble up through the water was a failure, the agitation produced being more than the delicate plants could stand.

It was also found in the laboratory experiments that the position of the jars in the window caused marked variations in the intensity of the growths. Those on the side of the window where the light was strongest gave the heaviest growths, except in one spot where the sunlight fell; there the growth was small. These facts led to a more extensive investigation to determine the effect of light of varying intensities. It was known, of course, that, in common with all chlorophyllaceous plants, diatoms will not grow in the dark, and it was also known that exposure to bright sunlight will kill them, but between the bright sunlight and total darkness there was a wide field for experiment.

A variety of preliminary experiments was made to determine the best method of regulating the intensity of the light and of securing such conditions that the results would be fairly comparable. They all showed that in the laboratory it was next to impossible to secure the desired result. It was therefore decided to make the experiments in the ponds themselves, under conditions as nearly as possible like those found in nature.

The method employed was an extremely simple one. It consisted of suspending bottles filled with water from the same source at different depths in the pond, the bottles being tied to a rope which hung from an anchored buoy. After a certain time the bottles were drawn to the surface and the water examined, records being kept of the number of diatoms in each sample before and after exposure. The bottles varied in capacity from 150 to 1,000 cc. In the first five experiments they were tightly stoppered, but in the later ones silk bolting cloth was tied over the mouths of the bottles, and inverted glass tumblers were placed above. The latter arrangement gave much heavier growths on account of providing better opportunity for the circulation of air and for the renewal of food supply.

The results of the experiments are given in tabular form at the end of this paper. Before discussing them, however, it will be appropriate to consider the subject of the nature and intensity of the light at various depths in the water.

This subject has not been as thoroughly investigated as its importance appears to demand, and most of the investigations that have been made were made upon the clear water of the ocean or of large lakes. Perhaps the most complete study of the transparency of water was that made by Prof. F. A. Forel upon the water of Lake Leman in Switzerland.

His experiments are fully described in the second volume of his recentmono graph, entitled, "Le Léman."* Three methods of experiment were employed. The first was that of the visibility of plates. This method, first used by Secchi in 1865 in determining the transparency of the water of the Mediterranean Sea, consisted of lowering a white disk (20 cm. in diameter) into the water and noting the depth at which it disappeared from view, and then raising it and noting the point at which it reappeared. The mean of these two depths was called the limit of visibility. The second method, known as that of the Genevan Commission, was similar to the first, but instead of a white disk an incandescent light was lowered into the water. This light when seen through the water from above presented an appearance similar to that of a street lamp in a fog, that is, there was a bright spot surrounded by a halo of diffused light. When the light was lowered into the water this bright spot first disappeared from view. The depth of this point was noted as the "limit of clear vision." Finally the diffused light disappeared, and the depth of this point was noted as the "limit of diffused light." Both the first and second methods were useful only in comparing the relative transparency of different waters or of the same water at different times. In order to get an idea of the intensity of light at different depths a photographic method was used. Sheets of sensitized albumen paper were prepared and mounted in a frame in such a way that half of the sheet was covered with a black screen, while the other half was exposed. A series of these papers was attached to a rope and lowered into the water; they were at equal distances apart, and so supported that they assumed a horizontal position in the water. They were placed in position during the night and allowed to remain twenty-four hours. On the next night they were drawn up and placed in a toning bath. A comparison of the prints made at different depths enabled the observer to determine the depth at which the

*F. A. Forel, "Le Léman," monographie limnologique, Lausanne, 1895.

light ceased to affect the plates and to obtain some idea of the relative intensity of the light at the different depths. To assist in this comparison an arbitrary scale was made by exposing sheets of the same paper to bright sunlight for different lengths of time.

The results of the experiments are given by Forel as follows: —

In Lake Leman the limit of visibility of a white disk 20 cm. in diameter was 21 m. The limit of clear vision of a 7-candle-power incandescent lamp was 40 m.; the limit of diffused light was about 90 m. The depth at which the light ceased to have any effect on the photographic paper was 100 m. when the paper was sensitized with chloride of silver, and about 200 when sensitized with iodobromide of silver. These depths were much less in summer than in winter on account of the increased turbidity of the water. The transparency of the water of other lakes, as shown by the limit of visibility of a white disk, is cited as follows: Lake Tahoe, 33 m.; La Mer des Antilles, 50 m.; Lac Lucal, 60 m.; Mediterranean Sea, 42.5 m.; Pacific Ocean, 59 m. It should be remembered that these are all comparatively light-colored waters, and that in them the light penetrates to far greater distances than in many of our brown-colored New England ponds. For example, in the Chestnut Hill Reservoir a plate lowered into the water at a time when the color was 0.92 disappeared from view at a depth of only six feet.*

The decrease in the intensity of light below the surface is due to two causes: First, the absorption of a certain portion of the light by the water; and second, the presence of fine particles in suspension, which act as a screen to shut out the light. The coefficient of absorption of light by water is practically unknown. It varies greatly, of course, with the quality of the water. Wild† gives the following figures for distilled water, and shows that the power of absorption increases with the temperature:

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*Recent experiments by the writer have shown that the limit of visibility may be determined most accurately by using a disk about eight inches in diameter divided into quadrants painted alternately black and white like the target of a level rod; and looking vertically down upon it through a water telescope provided with a suitable sunshade. It has been found that the limit of visibility obtained in this manner bears a very close relation to the turbidity of the water, and it seems quite possible that this simple experiment may be of considerable value in determining the relative turbidities of different waters.

†H. Wild: Ueber die Lichtabsorption der Luft. Poggendorfs Annalen, Anhang cxxxiv, 582, Berlin, 1868.

Temperature.	Intensity of light after passing through 1 dm. of distilled water.*
24.4° Cent.	0.9179
17.00 "	0.93968
6.2° "	0.94769

The reduction of light in passing through water is supposed to follow the law that as the depth increases arithmetically the intensity of the light decreases geometrically. For example, if the intensity of the light falling upon the surface of a pond is represented by 1, and if $\frac{1}{4}$ of the light is absorbed by the first foot of water, then the intensity of light at the depth of one foot will be $\frac{3}{4}$; the second foot of water will absorb $\frac{1}{4}$ of $\frac{3}{4}$; and the intensity at a depth of 2 feet will therefore be $\frac{9}{16}$, and so on. At this rate of decrease the intensity of light at a depth of 10 feet will be only about 5 per cent of that at the surface.

In regard to the quality of the light at different depths there is little accurate data to be obtained. In a general way, however, it may be said that the red and yellow rays are most readily transmitted.

The practical question to be decided by the experiments was not the exact amount of light necessary for the development of diatoms, but the depth below which they are unable to grow and the difference in the growths at various depths caused by variations in the intensity of the light. The observations here recorded are offered as a partial answer to these questions.

Plate I shows the results of one series of observations. Bottles were filled with Cochituate water and located in Chestnut Hill Reservoir at depths of 2, 4, 6, 8, 10, and 25 feet, where they remained from April 29 to May 13, 1895. During this time the temperature varied from 53° to 62°, and the color of the water in which they were immersed was 0.58 (Platinum Standard). The relative growths at the different depths are shown by the curve, the number of diatoms in the original water being indicated by the broken line. Near the surface, it will be observed, there was a vigorous growth, there being more than 25,000 diatoms per cc. Most of these were Synedra. At

*Forel considers these values too low, and with this the writer concurs.

greater depths the numbers were less, and at the bottom there were fewer than in the original sample. In experiments Nos. 3 to 7 the

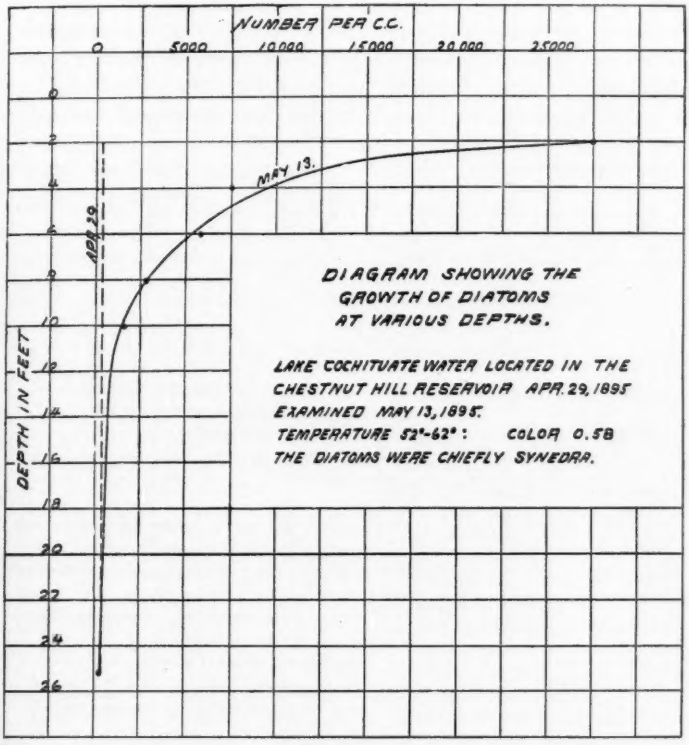


PLATE I.

"surface" samples were so placed that at times they were partially above the water, and therefore exposed to varying atmospheric temperatures and occasionally to direct sunlight. The effect was seen in a diminished growth. In those series the maximum growth was found just below the surface. In the other experiments the "surface" samples were immersed about six inches. These always gave the maximum growths. In Experiment No. 8 there were two "surface"

samples — one just above the surface and one immersed six inches. The latter gave the greater growth.

At what depth do the diatoms cease to develop, that is, at what depth is the intensity of the light so weak that it is incapable of furnishing the energy sufficient for their growth? The experiments show what we should naturally expect, that it depends upon the character of the water — its color, turbidity, etc. This is illustrated by Plate II., which shows the results of two series of experiments upon

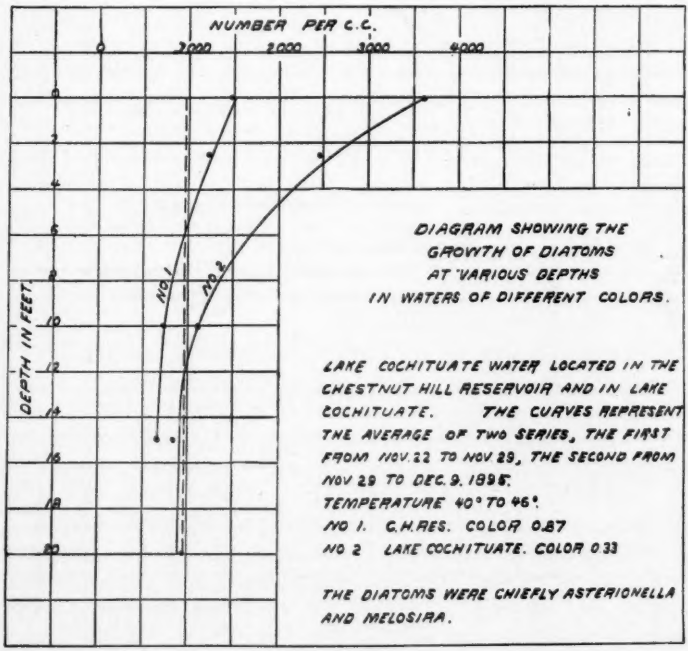


PLATE II.

water of the same kind located in Lake Cochituate and Chestnut Hill Reservoir. The former had a color of 0.33, while the color of the latter was 0.87. The difference between the two series is very striking. In the light-colored water the growths were heavier and extended to greater depths than in the darker water. Curve No. 1

represents the growths in Chestnut Hill Reservoir, and Curve No. 2 those in Lake Cochituate. The number of diatoms in the original sample is shown by the broken line. The point at which this broken line cuts the curves may be called the limit of growth. In Lake Cochituate this point was at a depth of about twelve feet; in Chestnut Hill Reservoir, six feet.

This limit of growth has been determined for each series of experiments. It varies considerably, but may be shown to be dependent largely upon the color of the water. If, for example, we divide the experiments into groups according to the color of the water, we obtain the following average values:

Number of Observations.	Average Color. (Platinum Standard.)	Average Limit of Growth in Feet.
5	0.29	15
5	0.60	12
2	0.86	8

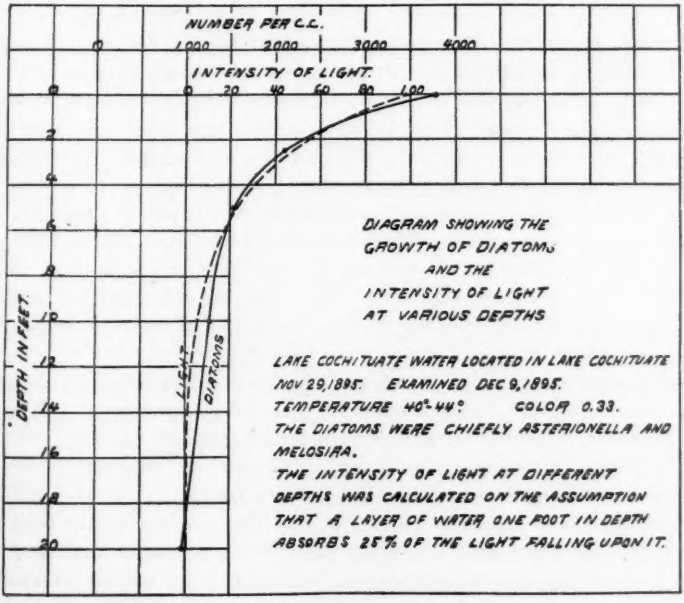


PLATE III.

Thus we see that in the dark waters the limit of growth is about 8 feet, while in the light waters it is about 15 feet. The limit of growth in a perfectly clear, colorless water is unknown, but the experiments of Forel and others indicate that it might be found at a considerable depth.

In order to appreciate better the fact that the extent of the growth of diatoms depends upon the intensity of the light, let us consider Experiments Nos. 9 and 10. These two series of experiments were made at a time when the temperature of the water in the reservoir was almost exactly the same from the surface to the bottom. The average of the results of these two experiments is shown on Plate III. In connection with these experiments the coefficient of absorption of light by the water was approximately determined in the laboratory, and the intensity of light was calculated for the different depths. These values are shown by the broken line on Plate III. The parallelism of this line with that representing the growth of diatoms is very striking.

Plate IV. shows the results of a series of experiments in which several examinations of each sample were made. These emphasize the fact that the rate of growth varies with the amount of light.

In Experiment No. 8 complete microscopical examinations were made. The diatoms, however, were the only organisms that developed extensively. Near the surface a few of the green algæ were seen during the first week or two. The Cyanophyceæ (chiefly a form of Anabæna) increased slightly at first and then began to disappear. Some of the infusoria developed to a slight extent near the surface. Whether this was on account of the difference in the amount of light or in the larger amount of food material near the surface is uncertain. It should be noticed that the amorphous matter increased from week to week, and that it was most abundant near the surface. As a supplement to this experiment, the bottle which had been suspended for three weeks at a depth of twenty feet was brought to the surface on November 30 and supported at a depth of one foot. On December 7 the diatoms, which at the bottom had decreased to 149 per cc., were 278 per cc. and in a healthy condition. They would doubtless have increased still more had not the experiment been accidentally terminated.

Diatoms are said to be positively heliotropic, that is, they tend to move towards the light. In some species this power is quite strong;

in others it is less noticeable. For the purpose of determining the heliotropism of the diatoms commonly found in water supplies,

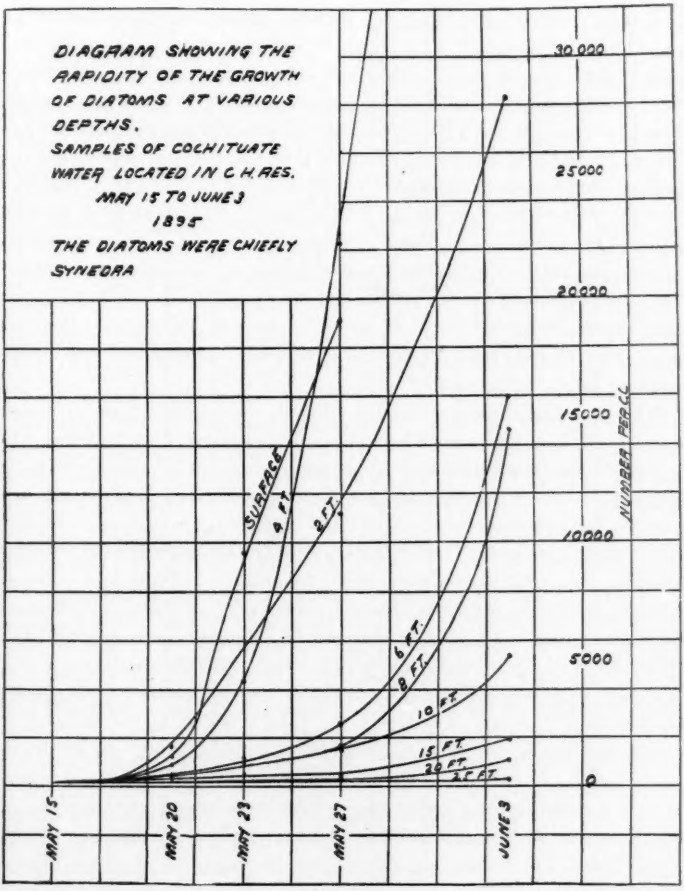


PLATE IV.

samples of water rich in diatoms were placed in brass tubes 3 inches in diameter and 32 inches long, having glass ends. One end was covered with a black cap, and the other end exposed to the light.

After varying lengths of exposure, portions of the water were drawn from each end of the tubes and examined microscopically. As an example of the results obtained the following may be quoted: Cochituate water containing 992 diatoms per cc. was exposed in a tube for twelve hours. At the end of that time the water at the light end of the tube contained 1,438, and that at the dark end only 320. Some of the tubes were inclined, to see if the diatoms would move upwards towards the light; some of them were placed vertical; in others the diatoms were given time to settle before the exposure was made. The experiments showed that most of the common genera tended to move towards the light while settling, but that having once reached the bottom of the tube they remained where they fell. They apparently did not possess the power of moving upwards towards the light — certainly not through any great depth of water. But while they could not rise of their own accord, slight currents of convection caused by varying the temperature of the water sufficed to keep them near the surface.

The inability of certain diatoms to rise towards the light of their own accord was also shown by another experiment. Glass tubes, $1\frac{1}{4}$ inches in diameter and 5 feet long, open at the lower end but closed at the top, were suspended in the reservoir at a time when Tabellaria and Stephanodiscus were numerous. The tops of the tubes were level with the surface of the water, and were so arranged that samples could be drawn from the closed ends. After these tubes were allowed to stand for a few hours it was almost invariably found that the diatoms had settled, and that the water at the top of the tubes was practically free from them. Other experiments along this line are in progress, and it is hoped that some interesting results will be reached.

The bearing which these facts have upon the seasonal distribution of diatoms is obvious, and we are now better able to understand why it is that their growths occur during those seasons of the year when the water is in circulation throughout the vertical. During those periods not only is food more abundant, but the vertical currents keep the diatoms near the surface, where there is light enough to stimulate their growth, and where there is an abundance of air. If this theory be true, it must follow that the weather has a marked influence upon their growth. We should expect that the greatest growths would occur on warm, fair days, when there is just wind enough to keep

the diatoms near the surface. On quiet days we should expect that they would sink in the water, perhaps below the limit of

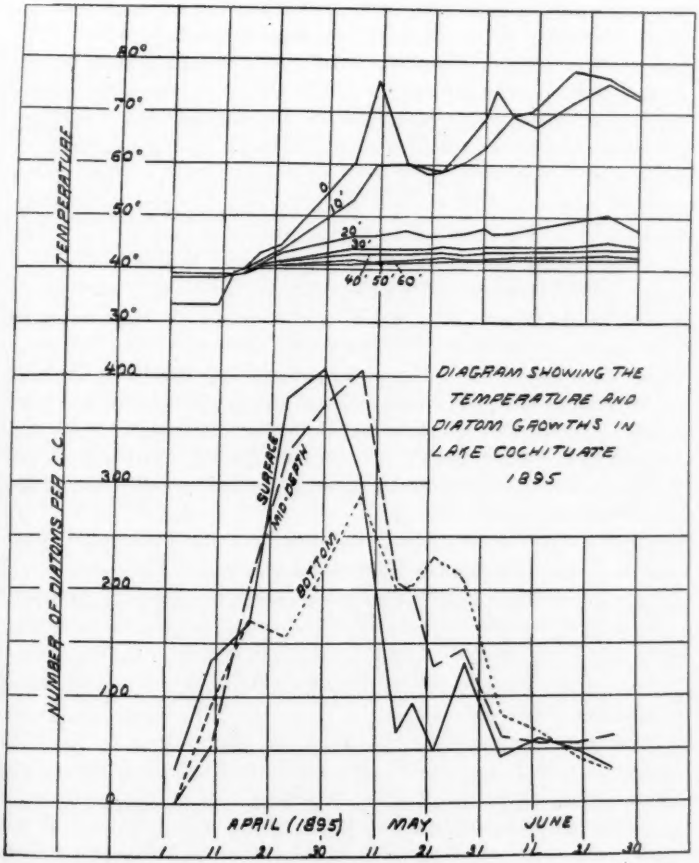


PLATE V.

their growth. During a long period of quiet weather they might sink even to such a depth that they would not again be able to reach the surface.

This is just what took place in Lake Cochituate in the spring o. 1895. In this lake there is almost invariably a heavy spring growth of diatoms, but in 1895 the growth was small. It began as usual, the diatoms being apparently in good condition. Early in May, however, there were a few days of uncommonly warm weather. The temperature of the air went above 90°, and the temperature of the surface water on one day was 76°. For almost a week the water was very calm. During this calm weather the diatoms settled rapidly, disappearing almost entirely from the surface. In the meantime the water became stratified, on account of the high temperature of the surface layers, and when once more the wind began to blow its influence was felt only ten or fifteen feet below the surface. The diatoms, having settled below that depth, were unable to rise, and consequently their growth ceased. These facts are illustrated on Plate V. In Basin III., which is not nearly as deep as Lake Cochituate, the growth of diatoms was arrested during the same warm, quiet period, but inasmuch as circulation afterwards reached to the bottom the growth began again, and continued until the next warm, quiet period, which occurred in June, checked it. In this connection it will be recalled that when the ice forms over a pond the diatom growths usually cease, though several notable exceptions might be mentioned.

Since the growth of diatoms depends upon the intensity of light, and since this is greater in colorless than in dark-colored waters, we may naturally expect to find the most extensive growth in light-colored waters. While it is true that food supply is quite as important as light for the growth of these organisms, yet it is true that to a certain extent the light-colored waters do show the greatest tendency to develop diatom growths.

The writer has recently compared the diatom growths in fifty-seven ponds and reservoirs of Massachusetts, as given in the reports of the State Board of Health. The result of this comparison is shown in the following table. From this we see that most of the heaviest growths occur in the light-colored waters, while in the very dark waters there are few. The table also shows that high chlorine, high hardness, and high nitrogen are favorable to their growth. In other words, an abundant food supply and a light-colored water are among their favorable conditions: —

Chemical Analysis. (Parts per 100,000.)		Number of Ponds and Reservoirs in which Diatoms are			
		Often above 1,000 per cc.	Occasionally above 1,000 per cc.	Usually between 100 and 600 per cc.	Always below 100 per cc.
Color (Nessler Scale.)	0 to 0.30	12	4	9	4
	0.30 to 0.60	6	2	4	0
	0.60 to 1.00	6	1	5	1
	1.00 to —	0	1	1	1
Excess of Chlorine	0	4	2	1	2
	.01 to .03	8	1	8	2
	.04 to .25	8	3	10	2
	.25 to —	4	2	0	0
Hardness	0 to 0.5	2	1	3	3
	0.5 to 1.0	7	4	5	2
	1.0 to 2.0	8	0	10	1
	2.0 to —	7	3	1	0
Nitrogen as Albuminoid Ammonia (In solution.)	0 to .0100	2	0	2	1
	.0100 to .0150	6	1	5	3
	.0150 to .0200	8	6	7	1
	.0200 to —	8	1	5	1
Nitrogen as Free Ammonia	0 to .0010	3	2	5	3
	.0010 to .0030	6	1	10	2
	.0030 to .0100	8	5	4	1
	.0100 to —	7	0	0	0
Nitrogen as Nitrates	0 to .0050	3	3	5	6
	.0050 to .0100	11	3	13	0
	.0100 to .0200	6	1	1	0
	.0200 to —	4	1	0	0

The writer has avoided reference to particular genera, for the reason that the experiments were hardly extensive enough to draw any general conclusions. The fact was noticed, however, that different genera require different amounts of light for their best growth. Melosira, for instance, do not require as much light as Synedra. In experiment No. 2 Melosira were found growing at a depth of ten

feet. In this connection it is interesting to note that Melosira sink in the water more rapidly than many of the common diatoms. It is very seldom, even during a vigorous growth, that they are found more abundant at the surface than at greater depths. It may be that on account of their tendency to sink in the water they have gradually become adapted to their dark environment, and are able to get along with less light than other diatoms. Asterionella, on the other hand, are slow in settling. Even in quiet weather they are found most abundant near the surface. They are known to be slightly motile, and it may be that, when supplied with a flood of light, their power of heliotropism becomes sufficient to overcome the effect of gravity and keep them near the surface.

In most ponds where diatoms flourish different genera come and go in a most irregular manner; they develop one after another, or they all grow at once; sometimes only one genus appears. No theory has as yet been advanced to account for their erratic succession. It is quite possible, however, that the cause may be found to be connected with their motility, their relative specific gravity and their sensitiveness to light.

In conclusion the writer desires to express his obligations to Mr. W. F. Murphy and Mr. C. E. Livermore, who have kindly assisted him in the various experiments.

EXPERIMENT No. 1.

Sudbury Water located in Chestnut Hill Reservoir, April 8-29, 1895.
Temperature, 39°–53° F. Color, 0.56.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Navicula.	Total.
April 8	All depths.	8	0	1	1	8	0	1
April 29	1 ft.	110	0	4	1,896	16	0	2,028
April 29	5 ft.	162	0	2	54	132	2	356
April 29	10 ft.	0	0	0	3	0	0	2
April 29	15 ft.	0	0	0	2	0	0	3
April 29	20 ft.	0	0	0	8	0	0	2
April 29	25 ft.	0	12	0	6	0	0	18

EXPERIMENT No. 2.

Cochituate Water located in Chestnut Hill Reservoir. April 29 to May 13, 1895.
Temperature, 53°–62°. Color, 0.58.

Date.	Depth.	Number per cc.					
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Total.
April 29	All depths.	94	196	3	11	15	319
May 13	2 ft.	4,040	910	20	22,010	550	27,530
May 13	4 ft.	570	80	10	6,800	120	7,580
May 13	6 ft.	380	650	26	4,510	284	5,850
May 13	8 ft.	650	840	26	1,304	100	2,920
May 13	10 ft.	154	1,380	10	80	0	1,624
May 13	25 ft.	16	132	0	88	28	264

EXPERIMENT No. 3.

Cochituate Water located in the Chestnut Hill Reservoir May 15 to June 3, 1895. Temperature, 62°-68°. Color, 0.57.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
May 15	All depths.	61	29	12	17	10	0	129
May 20	Surface.	196	28	12	896	104	0	1,236
May 20	2 ft.	108	32	20	1,408	56	0	1,624
May 20	4 ft.	116	56	36	584	80	0	872
May 20	6 ft.	88	20	32	288	28	0	456
May 20	8 ft.	56	8	24	136	24	0	248
May 20	10 ft.	0	0	36	220	8	0	264
May 20	15 ft.	48	24	8	192	28	0	300
May 20	20 ft.	16	16	32	204	16	0	284
May 20	25 ft.	80	36	20	104	0	0	240
May 23	Surface.	140	0	40	9.340	80	0	9,600
May 23	2 ft.	80	0	80	6,870	0	220	7,250
May 23	4 ft.	572	76	48	3,464	204	0	4,364
May 23	6 ft.	176	36	60	1,020	104	0	1,396
May 23	8 ft.	256	76	48	500	68	0	948
May 23	10 ft.	56	56	16	904	24	0	1,056
May 23	15 ft.	60	16	20	376	56	0	528
May 23	20 ft.	20	0	0	400	0	0	420
May 23	25 ft.	12	20	24	152	8	0	216
May 27	Surface.	200	0	60	18,800	40	0	19,100
May 27	2 ft.	...	0	0	10,100	80	20	10,200
May 27	4 ft.	140	100	60	21,550	290	10	22,150
May 27	6 ft.	70	50	90	4,580	90	0	4,880
May 27	8 ft.	188	56	40	1,184	160	0	1,628
May 27	10 ft.	60	92	8	1,256	64	8	1,488
May 27	15 ft.	104	56	16	316	16	4	512
May 27	20 ft.	40	32	16	404	...	0	492
May 27	25 ft.	0	16	20	96	16	0	148
June 3	Surface.	...	...	..	.....	...	0	.....
June 3	2 ft.	170	0	0	28,050	40	0	28,260
June 3	4 ft.	0	0	0	88,600	40	0	88,640
June 3	6 ft.	0	0	20	15,850	110	0	15,980
June 3	8 ft.	160	0	30	14,250	170	0	14,630
June 3	10 ft.	80	120	50	5,140	0	0	5,390
June 3	15 ft.	80	20	10	1,830	0	0	1,940
June 3	20 ft.	60	80	20	950	10	0	1,120
June 3	25 ft.	50	20	20	70	70	0	230

EXPERIMENT No. 4.

Cochituate Water (from depth of 30 ft.) located in lake Cochituate. May 31 to June 7, 1895. Temperature, 64°–70°. Color, 0.29.

Date.	Depth.	Number per cc.					
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Total.
May 31	All depths.	31	62	2	2	7	104
June 7	Surface.	350	0	70	380	0	800
June 7	2½ ft.	120	40	80	11,100	50	11,390
June 7	5 ft.	310	0	40	2,030	160	2,540
June 7	10 ft.	32	0	8	44	28	112
June 7	15 ft.	20	0	8	24	8	60
June 7	20 ft.	48	12	8	12	4	84
June 7	25 ft.	24	0	8	32	12	76
June 7	30 ft.	24	48	8	4	16	100
June 7	40 ft.	56	16	28	4	40	144
June 7	50 ft.	40	48	12	20	28	148
June 7	60 ft.	12	56	12	44	40	164

EXPERIMENT No. 5.

Sudbury water located in the Chestnut Hill Reservoir. June 5 to June 19, 1895. Temperature, 67°–72°. Color, 0.57.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
June 5	All depths.	6	0	17	12	72	13	120
June 12	Surface.	120	0	0	520	690	0	1,330
June 12	5 ft.	0	0	0	9,500	100	0	9,600
June 12	10 ft.	32	0	20	980	140	0	1,172
June 12	15 ft.	16	0	8	776	72	0	872
June 12	20 ft.	16	0	16	112	64	0	208
June 12	25 ft.	0	0	20	68	192	0	280
June 19	Surface.	..	..	..	....	..	..	.....
June 19	5 ft.	40	0	90	28,000	40	0	28,170
June 19	10 ft.	0	0	30	2,870	60	0	2,960
June 19	15 ft.	200	40	80	210	160	0	690
June 19	20 ft.	0	0	12	268	68	0	348
June 19	25 ft.	12	12	60	120	76	0	280

EXPERIMENT No. 5A.

Cochituate Water located in the Chestnut Hill Reservoir. June 5 to June 19, 1895. Temperature, 67°–72°. Color, 0.57.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
June 5	All depths.	0	0	27	4	8	10	49
June 12	Surface.	110	0	0	300	760	0	1,170
June 12	5 ft.	0	0	10	1,840	80	0	1,930
June 12	10 ft.	16	0	4	888	28	0	936
June 12	15 ft.	0	0	40	72	0	0	112
June 12	20 ft.	24	0	20	182	24	0	252
June 12	25 ft.	0	0	36	16	4	0	56
June 19	Surface.	..	..	..	....	..	..	.....
June 19	5 ft.	0	0	20	16,800	0	0	16,820
June 19	10 ft.	0	0	20	10,550	40	0	10,610
June 19	15 ft.	0	0	40	280	20	0	340
June 19	20 ft.	0	0	40	330	0	0	370
June 19	25 ft.	0	0	90	60	0	0	150

EXPERIMENT No. 6.

Cochituate Water (from depth of 60 ft.) located in the Chestnut Hill Reservoir. July 11 to July 26, 1895. Temperature, 69°–77°. Color, 0.58.

Date.	Depth.	Number per cc.					
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Total.
July 11	All depths.	2	30	8	4	0	44
July 26	Surface.	0	0	0	328	0	328
July 26	2½ ft.	0	32	0	8	0	40
July 26	5 ft.	0	0	0	4,400	0	4,400
July 26	7½ ft.	0	0	0	1,472	0	1,472
July 26	10 ft.	0	0	0	140	56	196
July 26	12½ ft.	0	72	0	32	12	116
July 26	15 ft.	0	60	0	48	68	176
July 26	17½ ft.	0	0	0	32	24	56
July 26	20 ft.	0	24	0	8	0	32
July 26	25 ft.	0	0	0	12	4	16

EXPERIMENT No. 7.

Reservoir Water located in Lake Cochituate and Basin 3. August 7 to August 17, 1895. Temperature, 70°–78°. Color: Lake Cochituate, 0.28; Basin 3, 0.68.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Cyclotella.	Total.
August 7.....	All depths.	0	0	25	0	84	3	112

Lake Cochituate.

August 17.....	Surface.	6	.0	0	78	102	0	186
August 17.....	2½ ft.	0	0	0	72	432	20	524
August 17.....	5 ft.	0	0	0	82	212	12	306
August 17.....	7½ ft.	..	..	..	..	..	..	...
August 17.....	10 ft.	0	0	0	20	184	30	234
August 17.....	15 ft.	0	0	0	2	50	12	64
August 17.....	20 ft.	0	0	4	8	56	24	92
August 17.....	30 ft.	0	0	0	6	46	2	54

Basin 3.

August 17.....	2½ ft.	0	0	18	28	340	26	412
August 17.....	5 ft.	0	0	0	52	158	46	256
August 17.....	7½ ft.	0	0	0	12	140	2	154
August 17.....	10 ft.	0	0	0	8	38	0	46

EXPERIMENT No. 8.

Cochituate Water located in the Chestnut Hill Reservoir. November 8 to November 30, 1895. Temperature, 40°–45°. Color, 0.83.

Date.	Depth.	Number of Standard Units per cc.						
		Diatomaceæ.	Chlorophyceæ.	Cyanophyceæ.	Fungi.	Infusoria.	Total Organisms.	Amorphous.
November 8.....	All depths.	463	4	487	1	36	991	280
November 12.....	Above surface.	1,278	30	580	4	27	1,919	376
November 12.....	Surface.	1,564	0	632	16	136	2,348	440
November 12.....	2½ ft.	664	5	532	0	95	1,296	308
November 12.....	5 ft.	676	17	488	8	20	1,209	344
November 12.....	7½ ft.	520	0	564	12	8	1,104	324
November 12.....	10 ft.	475	0	476	0	11	962	448
November 12.....	15 ft.	527	3	384	0	16	930	284
November 12.....	20 ft.	437	0	456	0	34	927	240
November 16.....	Above surface.	1,381	0	355	0	20	1,756	555
November 16.....	Surface.	3,075	0	680	0	117	3,872	685
November 16.....	2½ ft.	1,055	13	265	0	83	1,416	375
November 16.....	5 ft.	665	13	600	15	14	1,307	295
November 16.....	7½ ft.	440	20	460	0	7	927	310
November 16.....	10 ft.	543	15	515	0	67	1,140	375
November 16.....	15 ft.	375	9	465	0	0	849	270
November 16.....	20 ft.	514	0	375	10	0	899	280
November 23.....	Above surface.*	1,051	0	0	0	4	1,055	850
November 23.....	Surface.	3,464	0	460	0	0	3,924	860
November 23.....	2½ ft.	859	0	470	0	7	1,336	680
November 23.....	5 ft.	261	0	240	0	15	516	345
November 23.....	7½ ft.	103	0	215	0	4	322	310
November 23.....	10 ft.	65	0	155	0	0	220	190
November 23.....	15 ft.	....	..	...	..	...	....	....
November 23.....	20 ft.	130	0	40	0	4	174	255
November 30.....	Above surface.	....	..	...	..	...	....	....
November 30.....	Surface.	3,681	0	50	0	25	3,756	1,115
November 30.....	2½ ft.	1,043	18	220	0	5	1,286	965
November 30.....	5 ft.	248	0	110	0	4	362	700
November 30.....	7½ ft.	259	0	95	0	4	358	710
November 30.....	10 ft.	168	0	25	0	0	193	600
November 30.....	15 ft.	....	..	...	..	...	....	....
November 30.....	20 ft.	149	0	10	0	20	179	460

* Sample frozen.

EXPERIMENT No. 9.

Cochituate Water located in Lake Cochituate and the Chestnut Hill Reservoir.
November 22 to 29, 1895. Temperature, 42°–46°.
Color: Lake Cochituate, 0.33; Chestnut Hill Reservoir, 0.90.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
November 22.....	All depths.	824	244	8	24	8	8	1,116

Lake Cochituate.

November 29....	Surface.	2,820	675	20	0	0	20	3,535
November 29.....	2½ ft.	2,540	285	10	0	10	0	2.845
November 29.....	5 ft.	2,180	290	10	0	50	0	2,520
November 29.....	7½ ft.	1,485	495	5	50	5	0	2,040
November 29.....	10 ft.	840	110	0	0	0	5	955
November 29.....	15 ft.	290	205	15	0	0	10	520
November 29.....	30 ft.	520	360	10	40	20	0	950
November 29.....	50 ft.	285	520	10	0	15	5	835

Chestnut Hill Reservoir.

November 29.....	2½ ft.	1,070	125	10	0	10	0	1,215
November 29.....	5 ft.	770	230	5	0	20	0	1,025
November 29.....	7½ ft.	840	310	5	0	0	0	1,155
November 29.....	10 ft.	485	140	10	0	0	0	635
November 29.....	15 ft.	470	145	25	0	0	0	640

EXPERIMENT No. 10.

Lake Cochituate Water located in Lake Cochituate and the Chestnut Hill Reservoir. November 29 to December 9, 1895. Temperature, 40°-44°. Color: Lake Cochituate, 0.33; Chestnut Hill Reservoir, 0.84.

Date.	Depth.	Number per cc.						
		Asterionella.	Melosira.	Stephanodiscus.	Synedra.	Tabellaria.	Miscellaneous.	Total.
November 29.....	All depths.	625	150	13	17	0	5	810
Lake Cochituate.								
December 9.....	Surface.	3,010	685	35	60	0	0	3.790
December 9.....	2½ ft.	1,570	505	25	0	0	0	2,100
December 9.....	5 ft.	1,240	240	40	20	0	0	1,540
December 9.....	10 ft.	990	270	0	0	0	0	1,260
December 9.....	15 ft.	865	260	15	0	20	0	1,160
December 9.....	20 ft.	680	230	15	0	30	0	955
Chestnut Hill Reservoir.								
December 9.....	Surface.	895	435	40	60	50	0	1,480
December 9.....	2½ ft.	1,125	265	20	0	10	0	1,420
December 9.....	5 ft.	965	260	30	0	0	0	1,255
December 9.....	10 ft.	510	170	55	10	0	0	745
December 9.....	15 ft.	110	430	20	60	55	0	675

DISCUSSION.

Mr. FORBES. I was much interested in Mr. Whipple's paper. Two points I would like to touch upon. In the first place, we find that diatoms differ nearly as much among themselves as the larger plants we can see with the naked eye. I think there are now nearly 10,000 diatoms which have been named. Many of them have different habits. Mr. Whipple has spoken, I think, only of the diatoms Asterionella, Tabellaria, and Melosira, Cyclotella, Stephanodiscus, as behaving in a certain way. I have found in our Brookline reservoir the diatom Coconema and Cymbella occurring very freely at a depth of twenty feet. When the reservoir had been full for quite a long time and I had drawn it off, I found these two diatoms growing abundantly on the bottom. They are not free swimming, however. In the second place I would like to say a few words in relation to diatoms being kept near the surface by a movement of the water vertically. As most of you know we have in Brookline a covered reservoir and an open reservoir. The open reservoir is kept nearly full of water to be used in case of an accident to our pumps or a break in the main. Last winter, after the reservoir had been frozen over for several days, and the snow had covered the ice, and there had been no water pumped into the reservoir or drawn from it for several weeks, one quiet morning I cut a hole through the ice and took a sample of water quite near the surface, perhaps half a foot below the ice. I found the diatom Asterionella in large numbers in the water, which would seem to point to the fact that this diatom at least had the independent power of keeping itself near the surface. I have also found Synedra quite near the surface of the water under similar conditions, whereas other diatoms seem to prefer to live near or on the bottom. As, for instance, many species of Navicula, you expect to find crawling along on the bottom of rather shallow ponds. As I said before, the diatoms are extremely numerous, and they all have their own ideas of how they wish to live and intend to live. These are the particular points I wished to bring out.

Mr. WHIPPLE. Mr. Forbes' observation on the growth of Asterionella in the Brookline reservoir is an important one. Such facts should not be lost sight of when considering the relation between light and the growth of micro-organisms. Other cases similar to

that of Brookline reservoir might be mentioned. For example, in Waltham reservoir, which is an open one and which receives its supply from a filter gallery, Asterionella is found all the year round, and is almost equally abundant in winter and summer. In all these reservoirs where winter growths of diatoms occur we find an almost colorless water, and there is good reason to believe that even when the surface is frozen over the light penetrates the water to a considerable depth.

I agree with Mr. Forbes that we cannot insist too strongly that each micro-organism be studied by itself and its own life history determined. No two of them are just alike and no two of them obey just the same laws. In the case of the diatoms some are motile and others are not. The movements of diatoms have excited the interest and attention of microscopists for a good many years, but the cause of their movements has not yet been definitely established. Most observers agree, however, that these movements cease when the diatoms are placed in the dark. It may be possible that the Asterionella referred to by Mr. Forbes are an illustration of the verse of Scripture, "To him that hath shall be given." The Asterionella being present in a colorless water and supplied with a certain amount of light may have had their motility so excited that they remained near the surface, or possibly rose towards the surface where the light was stronger. Whether this was the case or whether there were slight connection currents in the water tending to keep the diatoms settling we do not know. A series of temperature observations taken under the ice at different depths and at different times would have been interesting in this connection.

MAKING CAST IRON PIPE.

BY JESSE GARRETT, PHILADELPHIA.

[*Read and illustrated by stereopticon, June* 10, 1896.]

In the reign of Henry IV. of France, a water engine was constructed for a special supply to the Louvre and the Tuilleries. On its front were illustrated the figures of Christ and the Woman of Samaria, and the name engraved upon it was "The Pump of the Samaritan."

For its universal efficacy in all phases of sanitation, in all ages of the world, the dispensing of water easily relates itself, not only to the *Well* of Samaria (of tender memory), but to the *mission* of the Good Samaritan, bestowing healing and joy by the wayside.

In this spirit men have reasoned together from the dawn of history how best to distribute to their craving fellows God's bountiful gift of water, and, in this spirit, men, and women too, still reason together to magnify the ministering office, to multiply the resources for fulfilling the mission of the Good Samaritan. In this spirit let us reason together to-day.

HISTORY OF PIPES.

The history of the various kinds of pipes for the conveyance and distribution of water, as regards the dominance of each, might be divided into four periods, as follows: The Age of Lead, The Age of Wood, The Age of Stone, The Age of Iron.

The transitions from the one to the other in the first three periods were not however, sharply defined, for each obtruded upon its successor for many centuries, and none obtained the domination that cast iron has now reached, and, to all present appearances, will continue to hold, notwithstanding the fact that steel-riveted conduits for large supplies and long distances appear to be winning the attention of engineers. Many occurrences would seem to imply, however, that we are yet in the very early educational period regarding the latter, while a century of cast iron has demonstrated its staying quality and established its claim to rule. The approaching important questions

of extending the London water system, reaching out to the lakes of Wales, one hundred and fifty miles or more from the city, and of New York and Philadelphia by going to the head waters of the Hudson and the Delaware, may bring steel pipe more closely to the attention of the engineering world.

But again, the double system, separating the water for domestic from that for public use, as now employed in Paris, is probably a coming query to be answered in all our large cities, in which cast iron pipe must necessarily retain its present strong position, and a friendly rivalry between the two constructions may not materially interfere with the success of either.

THE AGE OF LEAD.

Leaden pipes, as a distributing medium, appear to extend back to the dawn of history. In the ancient cities of Asia, Egypt, and Greece, they were used to convey water where the pressure was too great for earthenware. In the reign of King David, in a city of the Province of Zobah, afterwards Aleppo, lead pipes probably predominated, though some of stone or earthenware have been found, as also in the Temple of Solomon, and in public works of his reign.

In his engineering schemes Archimedes used lead pipes largely, and it was through lead that water was ultimately carried to the gardens of Babylon, after earthenware had been abandoned as unequal to the pressure. Greece, in all things tending towards refinement and luxury, led the advance in the most ancient times, and set the subsequent pace for Rome.

In Pope's translation of the Odyssey, we have these lines:—

> "The stream in pipes beneath the palace flows,
> And thence its current in the town bestows;
> To various uses various currents bring;
> The people some supply, and some the king."

Though in their wondrous works of utility and beauty the Romans as conquerors adopted the prevalent ideas, methods, and materials of the subjugated peoples, their marvellous powers of adaptation and the magnificent results obtained were worthy to rank as original creations.

From the foundation of Rome, contemporary in Biblical history with the reign of Zachariah, for four hundred and forty years the

people were content with the waters of the Tiber and such as their various pools supplied. In their earliest construction of water works they borrowed the idea of lead pipes from the Greeks. These pipes were made of leaden sheets soldered together, and were in various lengths, mostly, however, of ten feet, and from one to twelve inches in diameter. Various eccentricities of form are described; some were cylindrical, but mostly oval, with the seam at the apex.

It was, even in those early days, a subject of discussion, and by some seriously averred that lead pipes poisoned the water, and this question, so early raised, remains a question of debate with you to this day.

The distribution lines, carrying water to and through the bathing places and the houses, were the property of the state, and the use was granted to families and individuals, whose names were required to be engraved on the pipe, and these, in the excavations now going forward, locate the residence of this or that personage, and many men of note are so traced to-day to their ancient homes. At the period here described, within the walls of Rome were eighteen hundred palaces and fifty thousand houses of the people who numbered one million.

The mazes of these pipes through the streets of the cities of Babylon, Rome, Pompeii, and many others, bewilder the archæologist, and the student who attempts to follow his interesting recitals. In all these cities the trail of the water pipes leads to the verification of old story, and the unfolding of new, as thousands of tons of pipes are unearthed in the explorations.

The Roman Baths are most notable, especially those of Caracalla, 217 A. D., and Diocletian, 295 A. D., with their intricate network of pipes supplying cold water, hot water, and tepid water through separate systems, mostly of lead, some of wood, and a few of earthenware. It will be interesting to look at the figures from the standpoint

of the Water Registrar. The capacity of the Diocletian system, for instance, was equal to the accommodation of 18,000 bathers at once, and the daily period of the baths was about three hours; allowing a half hour for each bather, 108,000 persons were refreshed daily, with an expenditure of water in each of the three compartments, the tepid, the hot, the cold, of over 1,140,000 cubic feet, or, in all, about 25,000,000 gallons of water for one system of baths daily. But this, even, seems insignificant, when drawn from a daily supply of 385,000,000 gallons.

The cold water came directly to the "Frigidarium," from a reservoir supplied by one or more of the great aqueducts. The tepid water, similarly supplied to a great reservoir, was warmed by the sun, and conveyed thence in lead pipes to the "Tepidarium"; the hot water, drawn from other reservoirs, was heated in copper vessels, and passed on through them to the "Calidarium."

Besides these, were the pipe systems for their many beautiful fountains, surrounding which were seats inviting all classes to tarry and enjoy their refreshment.

Again were other systems of piping for private houses. Rudolfo Lanciani, a most ardent archæologist and poetic writer now exploring and writing, goes farther than indicated above and says: "At the crossing of roads there were fountains for the accommodation of travellers and their horses; in fact, the gentleness and tenderness of those happy generations went so far as to provide weary pilgrims with seats shaded by trees, where they could rest during the hot hours of the day."

For purposes of domestic supply, and in the general spirit of sanitation, Agrippa alone constructed seventy pools, one hundred and five fountains, and one hundred and thirty reservoirs. Truly, the ancients believed, as one of their writers said, in the most generous distribution of the "bounty of the gods."

Though in our many public parks and still-multiplying enterprises for the public good, we are not without commendable effort towards such benefactions as are described, we by no means reach the wondrous achievements of the ancients, and we may yet learn something from the heathen Samaritan.

From the decline of the old civilizations there is not much progress to note in water supply in any countries for many centuries. Wherever small, new systems were established, or old ones extended,

lead appears to have been still the prevailing material for distribution.

Not until the year 1236, is there much new record accessible. In that year, London began to lay a 6-inch main from springs at Tyburn, where the water was collected in a cistern of stone, lined with lead, situated some miles distant. This is supposed to have been the first attempt of that great city towards a public water supply, and even this small system took fifty years to complete; and it does not even appear that water was distributed to private houses until the year 1582. The pipes that were laid down in this primitive effort were dug up in 1745, and were of the old construction of soldered sheet lead. As time went on, different methods of manufacture came into vogue, and about the beginning of the sixteenth century they began to cast lead pipe in short lengths, vertically, and, later on, in longer lengths; the first pipe being cast and drawn upwards through its flask till the lower end was near the inlet gate, the metal of the second pouring fusing with the first, and so on, to the desired length.

A quaint, old chronicle of 1749 describes the stealing of water from the mains in public streets as follows: "This yere a chandler in Flete Street had by craft perced a pipe of the condite withynne the ground and so conveyed the water into his selar: wherefore he was judged to ride through the citie with a condite upon his hedde."

I find also a curious record about this time, which, although not altogether relevant to pipes, will be interesting to those of you who have water rents to collect. In 1439 the Abbot of Westminster granted the Mayor and citizens of London "one head of water," twenty-six perches in length, and one in breadth, with all its springs, in consideration of which rent the city is forever to pay at the Feast of St. Peter "two peppercorns." You may like to muse upon this whilst holding your quarterly celebrations, receiving the offerings from a glad public, and maintaining a sweet demeanor, at *your* "Feasts of St. Peter."

Henry VI. afterwards confirmed this grant, and a law was passed to put to death those who were found destroying pipes, which may be considered good positive evidence of the continued use of lead or wood, and circumstantial proof that cast iron had not come.

A French writer mentions lead pipe for a height of 400 feet, 20 inches in diameter, 5½ inches thick; also copper pipes for same

diameter and height, $1\frac{19}{12}$ inches thick. This writer says: "Cast iron is not used because it will not resist the loads of vehicles by which they would be likely to be broken, and it is impossible to get out any of the fragments."

The most ancient aqueduct for supplying Paris was that of Prés-Saint Gervais, and belonged to the Abbe St. Laurent. The hills about supplied it with water, through lead pipes, from a reservoir. About 1600, Henry IV., whose name occurs most frequently of any of the monarchs in the encouragement and promotion of water supplies, erected a pump, previously spoken of as that of "La Samaritaine."

A work written about 1700 cites, as one of the curiosities of Augsburg, Germany, towers to which water is raised through large leaden pipes, from which distribution is made to smaller pipes to one thousand houses and to public fountains, at a cost of *eight crowns yearly*.

Another old account describes fresh water as being obtained from the bottom of the sea by sinking large bells or cylinders of lead, to the upper portions of which were attached pipes of leather, from which, probably, our leather fire hose is descended.

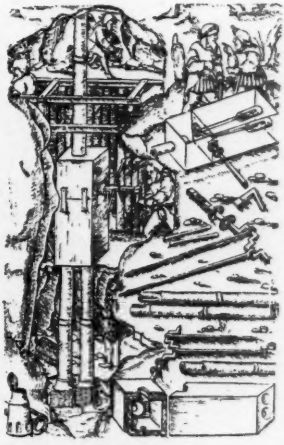
To conclude the episode of lead, which prevailed during the period spoken of in Paris, Glasgow, and other large cities, almost the entire system of London being of this material, the pipes in the Great Fire, in 1666, were melted, and, while the immediate substitute was of wood, an impulse was given towards a better pipe for water, and, under continued experiment and failure, a slow development progressed towards cast iron, which I will speak of and illustrate later on.

THE AGE OF WOOD.

The wood dynasty appears to have contested the field with lead almost from the beginning with a potency and persistency that, for many centuries, gave it a most important position in water supply systems, and enabled it ultimately to occupy the foremost rank for two or three hundred years until, itself superseded by cast iron, but with fitful manifestations of life, to this day. Ewbank quotes from "Pliny's Work on Gardens," describing the use of different kinds of wood. He says: "Pine pitch trees and allars are very good to make pumps and conduit pipes to convey water, for which purposes

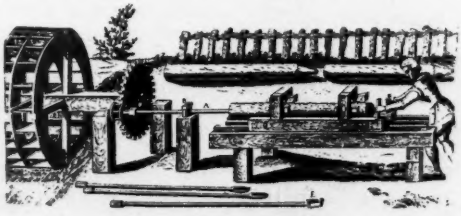
the trunks are bored hollow," and he supposes these to be of ancient origin. I do not know, but it may be this allar tree was a larger growth than we know, of the pithy alder or elder, which other accounts speak of as being used for such purpose. For instance, in

[*From Agricola's "De. re Metallica,"* 1556.]
BORING LOGS FOR WATER PIPE.



[*Agricola*, 1556.]
LIFT PUMP OF LOGS.

the Encyclopedia Britannica, dated 1797, I find the following: "Pipes for water, water engines, etc., are usually of lead, earth, or wood, the latter of oak or elder." *



[*From "Raisons des Forces Movantes,"* 1615.]
BORING LOGS—IMPROVED APPARATUS.

Nothing of more than ordinary importance occurred to disturb the relative position of lead and wood in the ancient practice, or in the latter slow development of water works in Europe, till after the fire

* Anglo Saxon, "ala." Elder, in Anglo Saxon ala tar, hollow tree.

of London, which has before been noted, when the use of wood, that had already been employed to some extent, began to supplant lead, until the latter for street mains was entirely displaced. For a time after the fire, water was distributed by water carriers with buckets.

The "New River Company," the oldest of the family of water works now supplying the city of London, was chartered about 1600 by James I. Its distribution aggregated a length of four hundred miles of wooden pipe, requiring frequent repairs, insomuch that the entire system was renewed about every twenty years. They were of the usual style of pump connections, were coated in a bath of lime water, and, with whiting and tallow, the joints were driven home. But the wastage was enormous, said to be about twenty-five per cent. These logs were in their turn replaced by cast iron as early as 1820, at a cost of £1,500,000. The many other companies then supplying London soon followed, and the most extensive equipment of wood pipe distribution ever in existence, passed away.

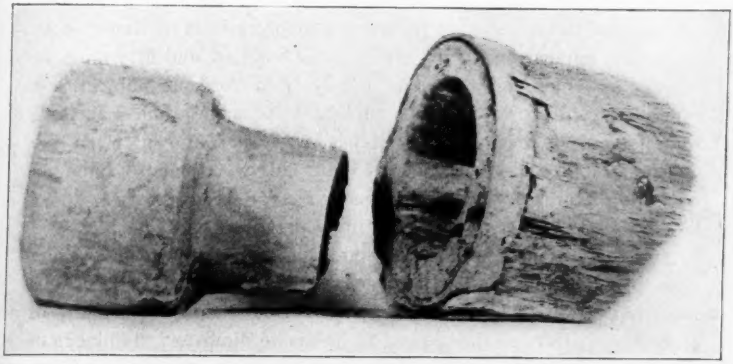
In addition to the wood pipes, there were also in use those of stone ware, of coarse glass, and in Peru and Mexico even silver water pipes were found at the time of the Conquest.

NOTE. — In the *Scientific American*, Sept. 22, 1883, can be found this description of paper pipes for water, which were made by "passing a continuous slip of hemp paper, the width of which equals the length of the tube, through a bath of melted asphalt, and rolling it tightly and smoothly on a core of the required diameter till the number of layers is sufficient to make the desired thickness, when the tube is strongly compressed — the outside sprinkled with fine sand, and the whole cooled in water. When cold, the core is drawn and the inside washed with a waterproof composition. These pipes were said to have great strength, when about one-half inch thick, withstanding a pressure of two hundred pounds, not broken by settlement, poor conductors of *heat*, and do not freeze."

The first water works at Philadelphia used wood for distribution until after the beginning of the present century, when their replacement by cast iron was begun, and of which I will speak more particularly later on.

The earliest water works of record, however, in this country were those of the city of Boston, built in 1652, and more sluggish and dilatory to advance after that, was our sister city, than can be conceived when we consider the wonderful pioneer service she has done now for many years. They were built, the chronicle says, for fire service and domestic supply. The name of the system was the

"Ancient Conduit," and consisted of a reservoir, about the region of Dock Square, spouting water round about, when needed, through the pipes of lead or wood. No advance beyond this is recorded till more than a century later (1796) when water was brought from Jamaica Pond through four pipes of pitch pine log, two of 4-inch bore, and two of 3-inch bore; the combined length of the two lines being about



WOODEN PIPE LAID FROM JAMAICA POND.

fifteen miles. This enterprise was conducted by what was called the "Aqueduct Corporation." In 1825, city ownership was advocated, under the then Mayor Quincy. Not till 1840 does it appear that wood was superseded by iron, at which time "a 10-inch main was laid to Bowdoin Square," and not till 1846 were the new city works begun. On July 4 of that year, Cochituate water was first introduced in barrels at Boston Common. To-day Boston may be said to lead the world in water works enterprises, and has under contract and in process of construction the most gigantic system of modern times.

The works of Detroit, Mich., were commenced in 1825, and first delivered water in 1827. The pumps at that time were driven by horse power, and the water pumped into an elevated "cupola," and from thence through pipes of tamarack logs, 4½ inches in diameter, to a reservoir 16 feet square and 6 feet deep, constructed of white oak plank. In 1830 the system was extended, and a ten-horse power steam engine was first used, the second one erected in Michigan.

The water by this engine was driven through a three-inch pipe to the reservoir, the first cast iron pipe used in Detroit.

The principal source from which wooden pipes are received at this day is from Michigan, where if anywhere it holds the "age," and there are probably more wooden pipes laid there for water than in all the rest of the country combined.

THE AGE OF STONE.

I pass by the splendor of the great stone conduits of Rome (nine or more in number and aggregating three hundred and fifty miles in length) as being, perhaps, too highly born for our subject. I cannot refrain, however, from quoting a passage from Lanciani, who "rejoices that cast-iron pipes were not known when the aqueducts were reared, because of the beauty the Roman Campagna now affords." In considering stone as a water conveyance, it will be more in its unique variety than in its prevalent character.

Among the ancients I find quoted from Herodotus an interesting description of a conduit to convey water, constructed by Emperlinus for supplying the city of Samos. It was one mile in length, of stone, bored through the centre, 13 inches in diameter, the blocks of three feet, cubical measure. On one end of each block was an annular projection to fit into a recess three inches deep in the abutting stone, a "spigot and faucet." This was laid at places on masonry of 200 feet span and 250 feet height. I find no account of the method of boring these blocks, but following up the thread, one of James Watt's principal assistants, about the beginning of this century, patented an apparatus for boring stone pipes, and these were used in the first work constructed for supplying Manchester, England, about 1810 to 1814.

These were bored from a soft limestone, but were found unequal to the pressure, and, in the fulness of time, were exchanged for cast iron, except for high points.

They were about two feet long, with spigot and faucet joints, sealed by Roman cement, from three to eighteen inches in diameter, and it is interesting to note the prices: 3-inch bore about 27 cents per foot; 6-inch bore about 90 cents per foot; 12-inch bore about $2.50 per foot; 18-inch bore about $3.65 per foot.

NOTE. — In the previous mention of stone pipes, I have passed by the earthenware, which are sometimes so classed, and in Rome were frequently used, connected with screw joints. Very ancient conduits have been exca-

vated in the Island of Cyprus, ten feet below the surface, and these were made of red clay, about one foot in diameter, with spigot and faucet joints, filled with cement and coated with bitumen.

Lanciana describes mains of stones, the mouths of which were of marble, grotesquely carved. These, he assumes, were of the sewer system of Rome, as, from their position, it would appear that they were placed to empty their contents into the Tiber.

THE AGE OF CAST IRON.

Regarding the discovery of iron, our own Professor Drown said, in an address some years ago, that all stories of original discovery developed from fancy, with a basis of truth; and this was probably the foundation of the legend that iron was first found after the large forest fires on Mount Ida thousands of years ago, which fused the ore lying on, or near, the surface of the earth.

At a general meeting of the German Iron Founders Association, held in Wiesbaden, Dr. Beck, of Biebrich, read a paper on the history of iron casting, in which he stated that "the first find of metal was a piece of iron which was discovered in the foundations of an Egyptian pyramid three thousand years before the Christian era."

During all the early ages of iron, it was only used in forged product for weapons of war or architectural purposes. The pillars at the gate at the Temple of Delhi weighed thirty-eight thousand pounds, were twenty-four feet high, sixteen inches in diameter at the bottom and twelve inches at the top, on which it is said that no method of cutting now employed can make a mark.

Cast iron was known to Holland in the 13th century, and stoves were cast at Elass in 1400. But tradition has it, which an ancient Roman writer records, that the temple of the "Great Mother" at Sparta is said to have been built by Theodorus, who first discovered the art of casting and making statues in iron. All this is necessarily vague, a condition which suggests a quotation from Dr. Greene, of the Boston Historical Society, in reference to the present disturbance of King's Chapel burying ground for the subway human conduit. "It is so full of bones and remains that I do not believe you could dig down to the depth of much more than an inch without turning up the dust of ancient worthies." The application is this; that in the dust of these "ancient worthies," it is impossible to verify the individual instance.

As with the metal itself, so its discovery in the form of cast iron was an accident which occurred at one of the early iron works in the Rhine Provinces, where a part of the "running" one day was found to be of different texture, and it was a problem for some time what to do with the strange stuff.

The first blast furnaces appeared in the Thuringian Mountains, which were almost identical in principle with the present furnaces, with the exception that hand or tread-mill bellows were used for the blast, from which the present mechanical blowers are an evolution. In 1377, the first cast iron gun was cast in Erfurt, and the famous Krupp was casting guns in 1818, so that it appears iron was mostly used for destructive, and not Samaritan, purposes through many centuries of its history.

In 1685, the first cast-iron pipes were used for the water service of Versailles, followed by screwed and flanged pipes. In 1708 the Quaker, Darby, patented the system of box casting, and in the following year started the famous Coalbrookdale Foundry, which in 1780 turned out the first cast-iron bridge. The first casting in the United States is said to have been made at Lynn, Mass., — a cast-iron pot, — which was exhibited at the World's Fair at Chicago.

In the region of Alba Longa, buried by the volcanic eruption which drove the Albans to the present site of Rome, no trace of iron is found, and its absence is still notable in the archaic tombs of Rome. The metal for their implements, of whatever kind, was of bronze, and the early Roman religious sentiment shows such an abhorrence of iron as to make it a profane innovation to use it in almost any form, especially in and around their sacred temples. This superstition continued after the Christian Era, even down to the fall of the Empire.

In their religious rites, if iron had in any way approached a temple or shrine, sacrifices were instituted to expiate the profanation; so that we can hardly wonder that their attention was not turned to it as a substitute for *lead pipe*. When iron tools came to be used for engraving, and were so employed on certain altar inscriptions, penitential sacrifices were afterwards offered by slaying a cow or a sheep on the altar.

Bronze plows were used long after the introduction of iron plows. The High Priests of Rome would not shave, or have the hair cut, with iron instruments.

The first mention of iron pipes, I find, was in an elaborate system built at Marli, near Paris, and set to work in 1682, costing one and a half millions of dollars. The account says: "They drew the water by short suction pipes from the river Seine, and forced it through iron pipes up the hill. They climbed to a height of five hundred and thirty-three feet by a series of reservoirs and pumps, but this system came to be known as a 'monument of ignorance,'" probably after cast iron established confidence as a pressure pipe.

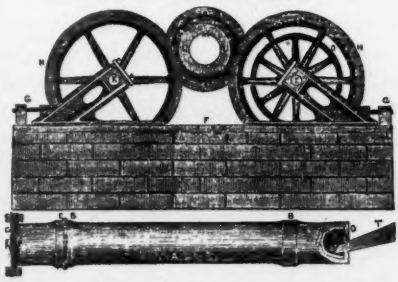
Agricola makes no mention of cast-iron pipes, although he shows three-legged pots of cast iron. Ranselli, about the same period, describes a hand-mill of a portable character, whose casing, he says, is made of iron, and its form and ornamentation is such that there is little doubt it was made of cast iron.

Peter Maurice, a German engineer, in 1582 erected, under the arches of London Bridge, sixteen pumps, seven inches in diameter, and thirty inches stroke, driven by a water wheel, and these were of cast iron, flanged at their lower end, bolted to a valve chest.

In 1835, it was estimated that over one thousand miles of iron pipe were in use in the various systems of London water works; the first iron pipes having been laid in 1746.

Later on we find that cast-iron pipes, nine feet in length, and fifteen inches in diameter, with ball and socket flexible joints, were laid by James Watt, across the Clyde, for the conveyance of water to Glasgow, and another of the same size in 1818, and a little later on, another of similar construction, of thirty-six inches diameter.

MOULDING PIPES WITHOUT CORES.



Among the curiosities of pipe-casting, we find the following English patents: one granted to Anthony George Eckhart, in 1809, for casting metals in revolving moulds, where the metal is poured into the mould, which is made to revolve very rapidly, and the centrifugal force causes it to fill up all parts of the mould; later on, another English patent granted to Andrew Shanks, in 1849. The process is very simple in idea; the small and of the

mould is nearly closed with a plate covered with loam, and the large end is also nearly closed by a similar plate, an opening in its centre being left for pouring in the metal. The mould is supported horizontally on friction wheels by which it is caused to revolve, and the fluid metal is distributed (by the centrifugal force, due to rapid rotation) over the interior surface of the mould; and as soon as the metal is cold enough to retain its form, the mould is opened and the pipe removed; if properly made one mould will serve for casting several pipes.

In an old Encyclopædia, I find that this method was used in Baltimore, but I have been unable to locate it in any closer way than by the mere description.

Cotemporary with the history of cast iron pipes in America is Peter Adams, a moulder and core-maker, born in Millville, New Jersey, in the year 1833. His grandfather, James Adams, was a soldier in the Revolutionary War. His father, Mark Adams, was born 1789, and was a moulder and core-maker at Weymouth, New Jersey, where he was engaged on the first cast-iron pipes made for the city of Philadelphia, from designs, and under the instruction and inspection of Frederic Graff, 1st, who was the then engineer of the Philadelphia Water Works, and father of the later Graff, who succeeded him in office. The first pipes made for Philadelphia were for the pumping main, of 16-inch diameter, delivering into the reservoir, the distribution still continuing throughout the city through wooden pipes. These pipes were cast direct from the melting of native bog ore, and the process was about as follows: in the beds where pigs were usually run, were moulds for pipe, which tapped the flow from the furnace, until one pipe was complete, then on to another mould, and so continuing for as many pipes as were planned for that pouring, using the surplus from the pipes for pigs as usual. The proprietor of these furnaces at Weymouth was a Mr. Richards, a native of the city of Philadelphia, and its Mayor at that time. After this, Mr. Adams thinks that the first pipe made at Millville, N. J., was about the year 1830, the inspector for which, under Mr. Graff, he remembers as one Louis Ort, who "was a good fellow enough, but inclined to be very particular unless he got one or two glasses of whiskey before beginning his daily inspection, in which case it was very seldom that he would reject a good pipe."

The first pipes made at Millville, as at Weymouth, were from the product of the bog ore furnaces, and at that time, of course, cast upon their sides, a series of gates, six or eight in number, used for running the iron from the furnace into the pipe moulds, which, at the proper time, were cut off, and the flow of iron continued to another series, or to the pigs, as the case might be.

As time went on, and the demand for cast-iron pipes increased, and sentiment ripened against using the melt direct from the ore, the proprietor of the Millville works, Mr. David Wood, designed and constructed special foundries for their manufacture. The practice of

PIG-IRON FURNACE, SHOWING THE RUNNING OF PIGS.

casting upon the side continued, however, until a much later date, and the first experiment of casting on end was made at Conshohocken, under the then proprietors, Bell & Colwell, about the year 1851. This was a 30-inch pipe, and the largest then ever cast in this country. Probably Mr. Adams is mistaken as to the date, as this is doubtless the pipe made for the city of Boston, spoken of in another place, the contract for which was placed at the Conshohocken works. The first fixtures for the vertical pipe were designed and made by one Alexander Russell. A pipe of this size was at that time of so great a novelty as to excite the curiosity of practical men

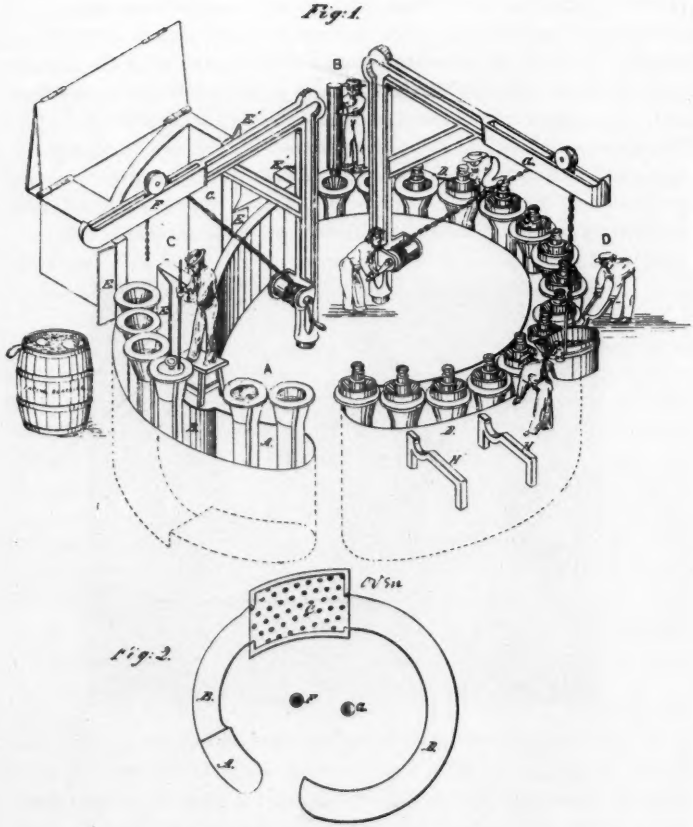
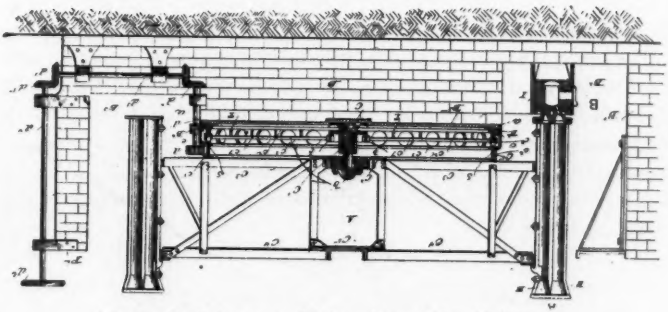


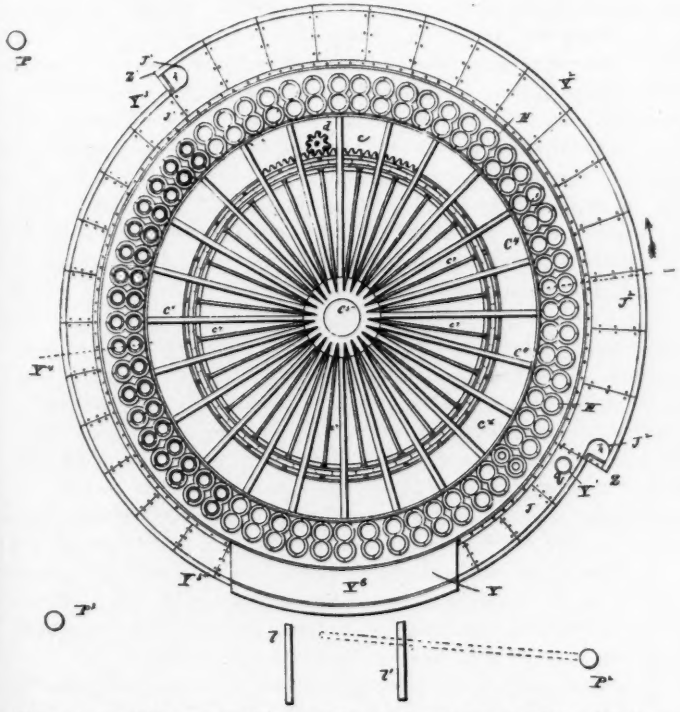
Fig. 1 shows an early English method of pipe casting "heads up." A prevalent practice now is to cast "heads down."

A is the flask.
B the core.
C ramming up the mould.
D pouring the iron.

Fig. 2 shows the plan of the pit with the oven, over which the moulds are placed in succession by the radial crane for drying, the heat ascending through the pipe. The present practice is to use closed ovens, uniformly heated, confining the moulds for hours.



After an English patent. Section of turn-table. Moulding pit.
A moulds. B oven.



Plan of a turn-table pipe-moulding machine, in limited use, showing a full pit of moulds. The pit revolves, carrying the moulds over a drying oven. No crane required.

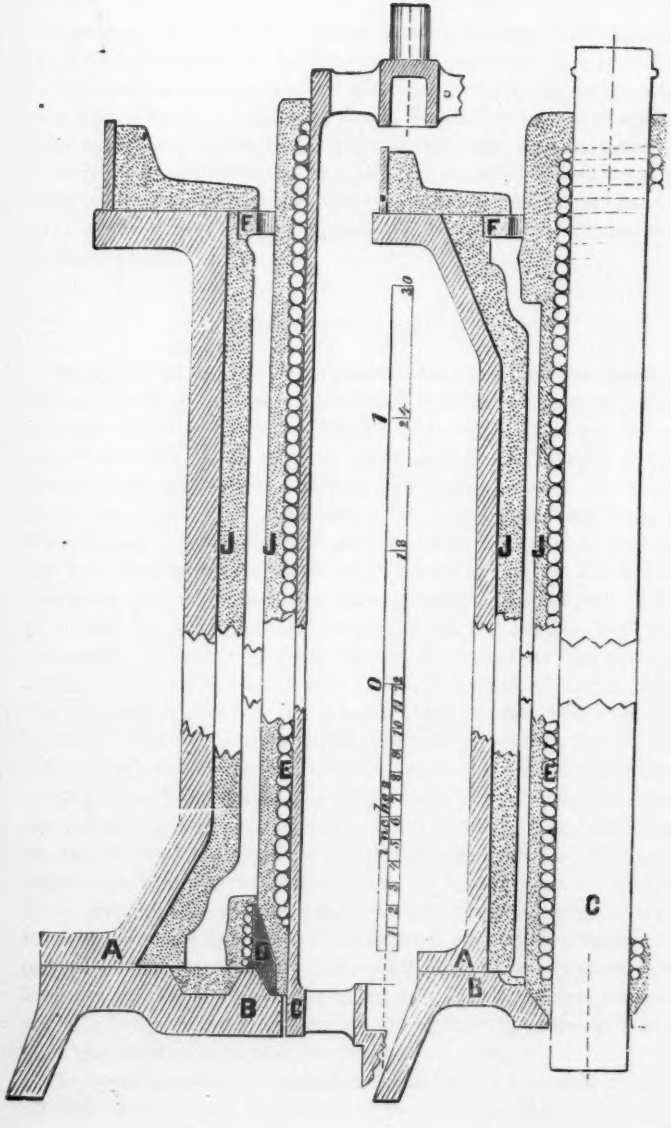
everywhere, and workmen from the Millville foundry were attracted to the Conshohocken works for the purpose of seeing so rare a production.

The original proprietor of the Millville iron works, as before stated, was David Wood, a brother of R. D. Wood, who succeeded him, and who afterwards added to his pipe works, from time to time, until their production became the largest in the country, and who was also thoroughly identified with iron and other industries, being one of the very earliest projectors and proprietors of the Johnstown iron works in Pennsylvania.

MANUFACTURE OF CAST IRON PIPE.

From the ore beds to the blast furnace, from the blast furnace to the cupola, is the course of the basic material for cast-iron pipes. As it comes from the blast furnace it is what is known as "pig iron," and each pig is cast to weigh about one hundred pounds. These before melting are broken in two pieces, in which size they go to the cupola. Good pipes cannot be made of the iron from one blast furnace. It is prevalent practice to use about four varieties of pig iron from various localities and grades of ore by which better results of pipe are obtained. These irons are all re-melted in what is known as the "Colliau" cupola, and, for the last ten years, principally with coke. Before that time were used the best grades of Lehigh, broken anthracite coal. A small portion of coal is mixed with the coke to give it body, and it is also an improvement in other respects. The fuel can be mixed in almost any proportion, from all coke to all coal, with a gradually decreasing speed of melting, although it is found that one quarter or less of coal does not materially reduce the melting per hour. The processes of melting, either by coal or coke, are somewhat similar, though in the use of coke the cupola tuyeres are a little higher from the bottom than for coal, the coke being lighter, taking a larger amount in bulk for what is termed the bed. The depth of bed of fuel depends altogether on the size and proportion of the cupola; the main point being to have the coke from four inches to six inches above the tuyeres, so that the first charge of iron will be above rather than below the tuyeres; if below, it is likely to be the cause of dead iron for the first few charges.

The usual practice for charging, depending as aforesaid upon the size and proportion, is as follows: First, the bed of coal or coke is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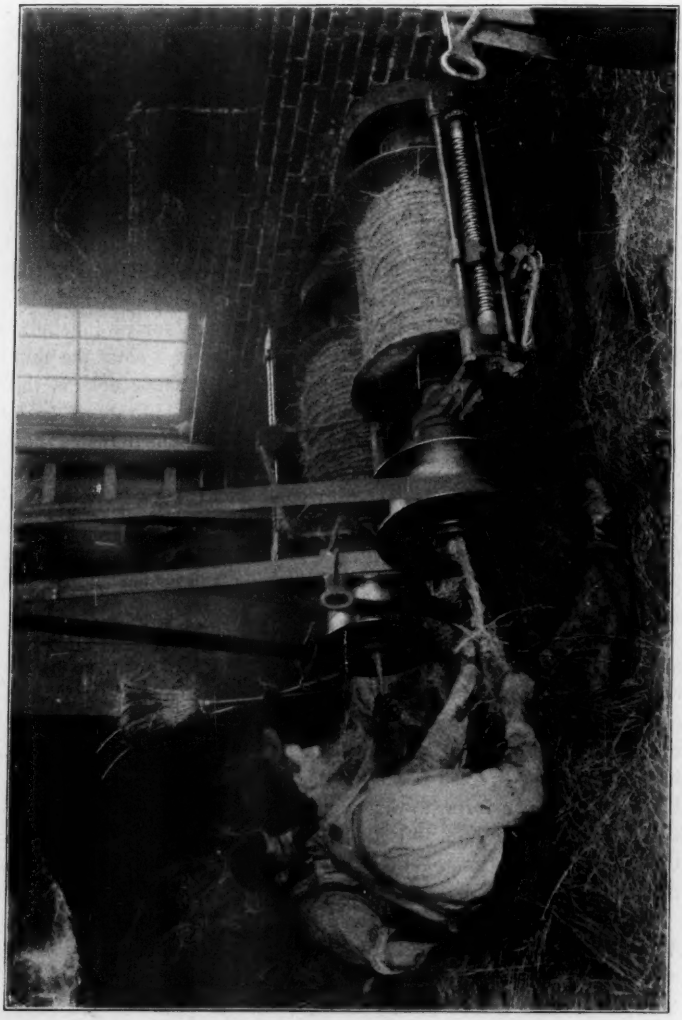
placed, say about fifteen hundred pounds, upon which is then put about four thousand pounds of pig iron; on this pig iron are placed three or four large scoop shovelfuls of limestone or oyster shells for flux; then comes a layer of about three hundred pounds of coke, on which again, the same amount of iron and flux. This routine is continued for five or six charges, when the amount of coke is reduced to about two hundred and twenty-five or two hundred and fifty pounds every charge, continuing as the process of melting goes on. The slag is tapped out at the back part of the cupola, at what is called the slag hole. It is placed an inch or two lower than the tuyeres, so that there shall be no molten slag running into them. The flux of oyster shells or lime is used to soften and liquefy the slag and make it fluid enough to run out at the cinder hole, and, by drawing off, as the melting goes on, you can run for an indefinite time. The cupola melts as fast at the end of the heat as at the first or even faster. About ten pounds of iron to one of coke is the general proportion of melting. When the fuel is entirely of coal, the proportion is about one sixth, the coke melting much faster than iron, but probably the iron melted by the coke not retaining its fluidity so long as when melted with coal, but the greater rapidity of coke melting, when a larger amount of iron is being reduced, probably more than offsets the longer life of coal melted, that is, in the quicker time of the coke melted, melting it does not exceed the period of its life before pouring.

In each sketch C is a cylindrical spindle, about which the core is formed (one half only of each mould section is shown, so as to avoid a greater reduction of scale). Around each spindle is first closely wound machine-made roping of straw, and then upon this a covering of tempered sand and clay is firmly packed. The spindle is then revolved in fixed bearings and its covering trimmed as in a lathe, by a proper form, to the exact shape and dimensions of both the interior of the pipe and its socket, and the bevel which is to centre it at the bottom of the flask or in the chill. This complete core is then ready to be placed in the drying oven.

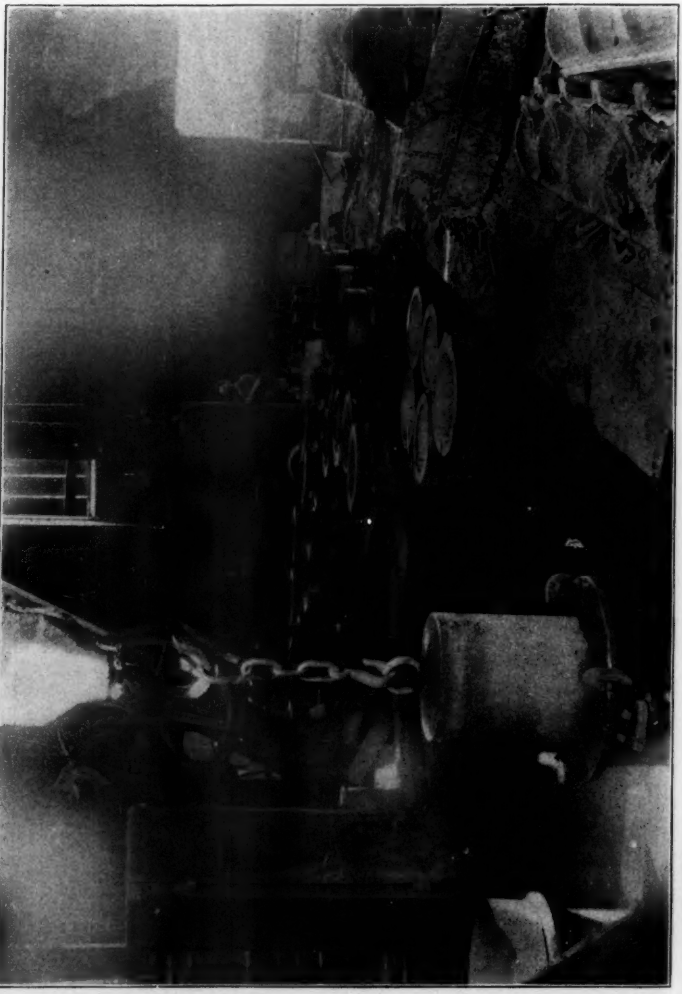
The outer case, A, is the flask, in which the mould is formed. Within the flask is placed and centred a pattern, the exterior of which conforms exactly to the exterior shape and size of the pipe. Tempered sand and clay are then rammed around the pattern to form the mold, and the flask is then ready for the drying oven.



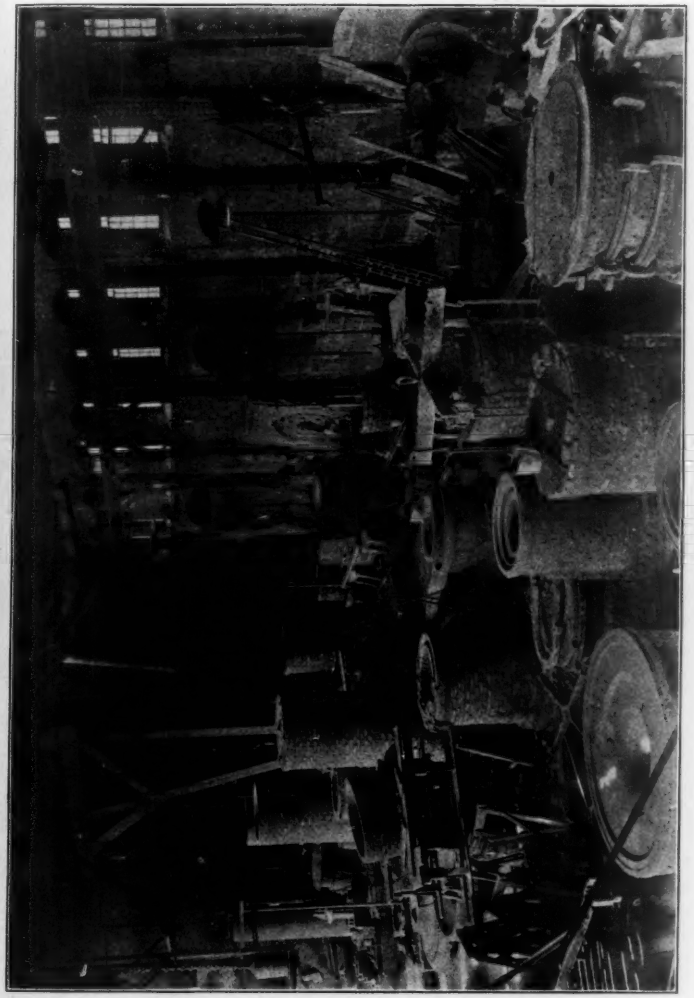
SPINNING HAY ROPE FOR SPINDLES.

WINDING THE ROPE ON SPINDLE TO BE COVERED WITH LOAM.

SPINNING HAY ROPE FOR SPINDLES.

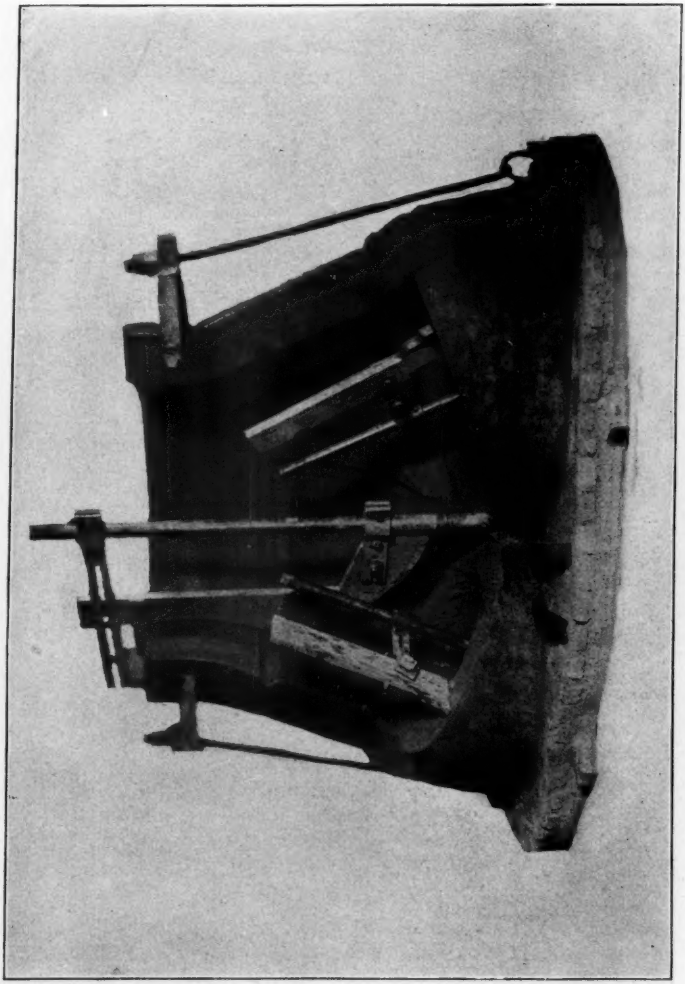


GENERAL VIEW OF PIPE PIT.



GENERAL VIEW OF PIPE PIT.

LOAM FOUNDRY.



MAKING MOULD FOR BREECHES PIPE.

CORE FOR BREECHES PIPE.

MAKING MOULD FOR BREECHES PIPE.

The metal socket ring, D, is also wound with straw roping, covered with sand, and accurately turned. The bead-ring, F, is formed in a turned-iron mould and dried.

When these several parts are dried and combined for casting the pipe, as they are shown in the sketches, the core is accurately centred by the bevel at the bottom and bead-ring at the top, and the space between mould and core will then conform accurately to the desired shape and dimensions of the pipe. The tempering of the sand and drying of the mould, so as to withstand the trying action of the molten metal, are matters that require the utmost care to insure perfect castings. The flasks are finally placed on end in the pit, preparatory to pouring, so as to secure a solid casting, cylindrical in bore, and of uniform thickness upon all sides.

The molten metal is then drawn from the cupola into the ladle and transferred within reach of the pit crane, by means of which it is lifted and poured. After several pipes have thus been cast, the emptied ladle is returned to its truck, and the crane used to quickly lift out the spindles, the hay-rope covering having meanwhile been burned away, admitting of their easy withdrawal; and the pipes are thus allowed to contract freely in cooling. As soon as properly cooled, the flasks and pipe are together lifted from the pit, when the clamps which have served to hold the sections of the flasks together are removed, and the pipes permitted to pass on to the cleaning skids. Single flasks are used for pipe of larger diameters, while in modern practice double and sometimes triple flasks are used for pipe of the smaller diameters.

COATING FOR CAST IRON PIPES.

Humber says: "To avoid oxidation, as far as possible, the metal should be selected, uniformly homogeneous, close and hard in texture; impure, soft foundry iron rapidly corrodes, the close gray and white iron being less destructible than any other." It is quite probable that the modern foundry practice will widely disagree with the opinion above expressed, but it was this condition of foundry knowledge that excited the inquiry of how to protect pipes from oxidation.

In 1866, experiments were made by the French Navy with a varnish of a mixture of sulphur, resin, tar, gutta percha, ceruse, and

turpentine. Pipes so treated were immersed in sea water for a year, and reported quite free from rust.

During these experiments, iron was galvanized by dipping it in boiling zinc, but the preparation was found to blister and peel off, and it was also subject to galvanic action. This was probably similar to the later preparation applied to what was called the "calomeine" process.

Latham, an English engineer, cites an instance at Croydon, in which the subject was a 12-inch pipe, 5/8 inches thick, tested under a pressure equivalent to a 500-feet head. In service it burst under a 150-feet head, in several parts, after a heavy rain followed by snow. Spon calls the condition that may so result, "hide-bound," wherein the texture of the pipe may be affected by sudden extreme change, or even a slight variation of temperature, cold weather being specially favorable to such.

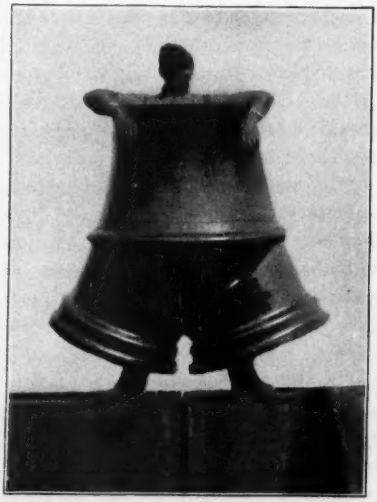
Edison has said that the very few successes he has attained are the results of multitudes of failures, and, in this way, came about the prescription of Dr. Angus Smith, which seemed to reach the proper treatment of the disease. The ingredients of his preparation were simply gas tar, Burgundy pitch, oil, and resin. The pipes, under his experiments, were first dipped while hot, but afterwards it was thought to produce better results to dip them cold, as the composition, in contact with highly heated iron, was injured and did not adhere as well. Five or six per cent linseed oil was a part of Dr. Smith's prescription. This was forty years ago, during which lapse of time modifications have been found to be necessary, desirable, and efficient, as well in the coating as in the iron mixtures and general processes of manufacture. An interesting, special coating for pipes, carrying water from coal seams, is as follows: the pipe was exposed three hours in a bath of hydrochloric acid, then dipped in water, afterwards washed with a mixture, thirty-four parts silica, fifteen borax, two of soda, then exposed in a retort to a dull, red heat, then another coat on the inner surface, and exposed to a white heat for twenty minutes.

The coating which mostly prevailed for the inside of stone, terra cotta, or masonry, was a stucco made of chalk and crushed tile or kindred substances.

In the groping for adequate protection against the action of water, the pipes were sometimes lined with resinous pine.

In searching for the beginnings of cast-iron pipe, it has seemed surprising that a public demand, which has reached, for purposes of *water supply*, at least 500,000 tons of cast-iron pipe annually, and for gas distribution, not less than 100,000 tons, should have a history so shrouded in obscurity; we might say, like the excavations in King's Chapel burying ground, to which Dr. Green alludes.

The water supply system of the United States aggregates a length of 50,000 miles of cast-iron pipe, and a value of $600,000,000, embraced in 2,000 cities and towns, of which it will be interesting, perhaps, to specify that the daily supply of Chicago is about 250,000,000 gallons, that of Philadelphia about 200,000,000; New York 190,000,000. In my researches in this direction I found about the largest supply per capita is in the city of Alleghany, about 250 gallons; in Buffalo, 186 gallons. London comes down to the consumption of 40 gallons per capita, and the lowest quantity of the present period, I find recorded, is in the city of Howrah, India, where, with a population of 125,000, the supply is 1,250,000, or ten gallons per head. At the end of the 17th century, however, the supply to the city of Paris, was about five pints per capita.



BREECHES PIPE.

DISCUSSION.

Mr. NOYES. Mr. Garrett's paper was exceedingly interesting to me from the fact that it presented the inside working and details of a branch of engineering work which we as engineers do not get very much of a chance to see. I am always jealous of every opportunity to obtain this information, especially when it comes from men who are personally engaged in the work.

I was particularly interested in the statement of Mr. Garrett that the use of four different kinds of iron is essential to the making of the best pipe. In my early work I took up the various specifications of engineers of repute, thoughtful men, men presumed to know their business, and I studied their specifications, and followed them, making such modifications as seemed wise to me to adapt them to the special work I had in hand. There were some sides of the question I was not then familiar with, but I felt it was safe, in view of the fact that men of such high repute had called for certain conditions in the casting and classes of iron used, to incorporate those conditions in my specifications, and did so. But since those earlier days I had had an opportunity to visit various foundries and to talk with the superintendents, and of late I have modified my specifications somewhat; and yet I find that there is still considerable to study and to learn.

In one form of specifications that is quite generally used, it is carefully provided that the pipe shall be of good gray iron and that no scrap will be used. But if you go to a foundry you will find the scrap pile there and you will see them using it.

Mr. GARRETT. I will only say a few words on this matter, because I have repeatedly averred I don't know anything about it. As to the use of scrap iron, I will say that in my visits to the foundry yards, I have never happened to see any scrap except the piles of scrap that resulted from broken pipe.

Mr. NOYES. I refer to commercial scrap; I have seen that at the foundries.

Mr. GARRETT. I, myself, have never been aware that any such scrap was ever used in pipe. It may be used, however, and probably Mr. Prince can tell you about that a little more accurately than I can. I know that the pipes that are rejected for technical reasons are broken up, and that the iron recovered from them is put back into the cupola and goes into pipes again; and that has always been

recognized as very good practice, and as not reducing the character of the pipe in any degree. As to other scrap, I know nothing whatever. I have never known that there was any other scrap used in reputable foundries for making pipe.

Mr. PRINCE. As I stated last night to Mr. Noyes we used almost no outside scrap, that is, commercial scrap. Occasionally we get a car load of large machinery scrap. This is always a high grade of iron, such as is generally used for high grade machinery. This we can use and do use occasionally, although I do not suppose in the last eight years we have averaged more than two car loads of it in a year. It is simply an occasional lot, and of course, so small a quantity cuts no figure really in our work. But aside from that, the scrap which we do use is fully equal to the grade of the iron which goes into the pipes, that is, it is usually 2X iron originally. The ordinary scrap, as I said before, we do not use at all. The scrap which results from pipe is fully equal to the pig iron in every way, because it is simply the first melting of pig iron, and any trouble which might arise from that special mixture would show itself in the pipe. If it results in iron which is brittle, cold short or red short, we are aware of it as soon as the pipe come out. All that pipe is put one side, and is not used except in very limited quantities. We understand the danger of it and of course guard against it in every way, because an excessive amount of that sort going in would result in another lot of bad iron. That may be used possibly to the extent of half of one per cent or one per cent of the mixture, and that, of course, as you see, is so small an amount it can exert no practical effect.

But ordinarily that is only a small part of the scrap. The other scrap comes from pipe which have been rejected on account of blow-holes or sand-holes, or some of these technical defects which the engineers are so particular about. Those pipe are broken up, and they are equal to pig iron in our estimation. They are fully equal to the original pig iron, and in fact better, because they have been tested and found to be a good mixture. And while it is scrap to the extent that it is bad casting, that is, a casting which has been broken up, it is not scrap in the ordinary acceptation of the iron trade, that is, it is not stove plate and grate-bars and all that sort of thing. So we may say that practically the use of scrap, as far as we are concerned, is eliminated. It is for our interest to use nothing

but what will make thoroughly good pipe; and it is hard enough to make pipe which will suit the engineers, even with the best of iron.

The PRESIDENT. How do American pipes compare with the English pipes in strength of casting?

Mr. PRINCE. I cannot answer that, Mr. President, for I am not familiar enough with the English results. I will say in regard to the tensile strength, that I have made many tests of pipe which have run from 20,000 to 23,000.

The PRESIDENT. Is the bar test a good test of the strength of pipe?

Mr. PRINCE. It is as an auxiliary. I do not consider it a good test apart from the inspector's work. A good inspector, who understands his business thoroughly, can tell what the iron is as he goes over the pipe and inspects it generally. The question of shrinkage and so forth will come in, but he can tell very closely whether the pipe is good or bad. A test bar, while it may be poured from the same mixture, is poured into a different mold, is subject to different conditions, and may not show the same results as are shown in the pipe. As an illustration of that I will cite a recent case where test bars showed a deficient strength, while the pipes themselves, which were rejected and broken up, showed some of the toughest iron I have seen for a long time. They were pipes such as we could usually break with one or two blows of a drop weighing two thousand pounds, and yet the drop would strike them and bound off several times without cracking them, showing that in that case at least the test bar and the pipe were not the same, but that the pipe was much better than the bar.

Mr. NOYES. I think in discussion among ourselves last night, you took exception to some special clauses which are frequently put into specifications with regard to the class of iron, and the freedom of the iron from certain substances; perhaps you will say something to the Association with regard to that.

Mr. PRINCE. My point there was simply making a little fun of some specifications that are drawn, showing the way that a clause will descend from generation to generation in the specifications. I have an impression that many specifications are made up with mucilage and a pair of scissors, and embrace certain clauses, grammatical errors and all, which have come down from previous years. The clause I spoke of particularly to Mr. Noyes was this one, which I

believe now appears in the Philadelphia specifications, that "it shall be entirely free from uncombined carbon when seen under the microscope, and shall admit of being easily drilled or cut." The very essence of gray iron is to have uncombined carbon in it, so far as I have been able to find from any authority I have questioned, and I have asked a good many. Iron that is free from uncombined carbon is simply white iron, and I never have yet found an inspector who is ready to take pipe made out of white iron. It cannot be cut, it cannot be drilled, and it is about as brittle as glass. The gray iron owes its grayness to carbon which is not in combination. The point was brought up more as showing some peculiarities of the specifications, and with how little care they are sometimes drawn.

The PRESIDENT. What percentage of free carbon would there be in gray iron?

Mr. PRINCE. That varies, of course, with the grade of iron. The average grade that is used in pipe-making contains from 2.5 to 3.75 per cent. It is largely dependent upon the per cent of silicon present, although it is influenced by the other constituents present in a less degree.

Mr. GARRETT. In connection with this subject, I would like to make two or three general remarks. Mr. Noyes spoke of the allusion I made last evening to four different kinds of iron. The four different kinds of iron I had in mind were the peculiar kinds of iron, chosen from different parts of the country, because of the qualities contained in each that are found to combine best in making up the mixture for cast-iron pipe. While the manufacturers may have what they call some manufacturing secrets of their own, which they do not propose to give away, as far as these discussions are concerned, we are very glad to answer your friendly questions. Now, Mr. Prince says that there are two carloads of scrap used in his foundry probably during a year. The out-put of the foundry he has the management of is not less than 40,000 or 50,000 tons a year, 150 to 200 tons a day. Therefore, two carloads of scrap, even if it were pretty bad scrap, would n't cut much of a figure.

Mr. NOYES. I might say, Mr. President, in justice to the foundries which Mr. Prince and Mr. Garrett represent, that I do not know that I have ever seen there the commercial scrap pile; but there are other foundries where I have seen it, and what called my attention especially to the matter, was, that I dislike to put out

specifications containing clauses which ought not to be insisted upon; and if better pipes can be made by the use of scrap iron, or iron which has been worked over, and has thereby become tempered, and works better in connection with the pig iron, as it is claimed by some superintendents it does, I believe, as engineers, we should eliminate from the specifications the requirement that it shall not be used.

Mr. GARRETT. I am glad Mr. Prince has touched upon what I said about the regeneration of iron. He told us last night that the kind of scrap they used in small quantities was not such as was objectionable in the making of any pipe, and if there were any objectionable features in the scrap they went out through the slag-hole. Is that right?

Mr. PRINCE. Pretty nearly right.

Mr. GARRETT. Well, will you please make it all right?

Mr. PRINCE. Well, Mr. President, the point is largely this: The question of the regeneration of iron, spoken of by Mr. Garrett, is a little peculiar, perhaps. Iron of a given composition is not helped at all or changed at all by repeated meltings if it retains the same chemical composition. It is all a question of having the right chemical composition. You have a certain per cent of the iron, and a certain per cent of silicon, of carbon, of sulphur, of maganese and of phosphorus, — those are the elements which make up a good mixture. Now, if iron in the form of scrap, resulting from one or two previous meltings, has an undue percentage of an injurious element in it, or an element which in cases may be injurious, it is simply a question of putting another iron with it which will supply that which is lacking in the mixture, so your result mixture may be of the proper chemical composition. The old belief that iron is improved in itself by repeated meltings I think is almost entirely passing away as the result of the experiment and discussion which has been going on in the foundry world during the last two or three years. The question has been very fully ventilated, and we are settling down now to the view that there is nothing especially unknown or peculiar about iron. If you have iron with a given chemical composition you are pretty sure to get a given physical strength. We are far from knowing all about it yet, but we are still studying very hard. If you take poor iron, iron that is low in certain elements, and mix it with another iron which is rich in those elements, in other words treat it so as to get a mixture which has the right percentages of the various elements which you want, it results in what is known as the regeneration of scrap iron.

I think the point Mr. Garrett had in mind was this, that when iron is used which is coated with rust and dirt, the foreign matters largely go out of the slag-hole, and do not go into the iron.

The PRESIDENT. I have been examining the interiors of large pipes lately, and one pipe will be clean and smooth on the interior, while the next pipe will have concentric rings going all around it, sometimes one-sixteenth of an inch in thickness. Can you tell me the cause of them?

Mr. PRINCE. Probably the giving of the hay-rope which is put on first, or some coil of the rope below the surface which is a little too large, or something of that kind. The pressure of the iron down at the bottom of the mold is a great many pounds and perhaps it pressed the mold in a little.

The PRESIDENT. The rings I speak of have the appearance of running around the pipe, not completely around but perhaps half way.

Mr. PRINCE. Those would be what are technically known as core swells, the result of the core giving a little. If we could make an absolutely solid core, that is if we could take the iron spindle and put the mud on it without any intervention of the hay-rope, then we would have it perfectly solid, and that would make the ideal core. Collapsing spindles have been used in this way. But the trouble with all collapsing spindles we have had in this country (they have been used in England, perhaps with more success) is that they are apt to lose their spring and elasticity after a while and to give trouble from other causes. So that the old way of using a spindle, winding a hay-rope around it and then putting on the two coatings of mud, obtains still in all the larger foundries in this country. But unless that core is made in the most solid and careful manner, it is bound to give and cause a core swell. The core is made an eighth to a sixteenth of an inch larger at the bottom than at the top to allow for that compression.

Mr. GARRETT. Before leaving this question I wish to make one inquiry of Mr. Prince. You speak of the different chemical qualities or different chemical constituents of the iron. Now, the choice of the four different grades of iron used, assuming that there are four, is made for the very purpose of getting the different constituents that go to make up the proper chemical combination for iron pipe, as I understand it. Now am I right in saying, as I think I did in my paper, that we use about one quarter of southern iron, and

that it is not found to be desirable in the eastern foundries to use more than about that proportion of southern iron, as it has component parts that go to destroy the best results? Is that true?

Mr. PRINCE. Well, that is hardly true, Mr. Garrett.

Mr. GARRETT. Well, I want you to tell us the truth about it.

Mr. PRINCE. It cannot be said that Southern iron tends to destroy the best results. In the first place, the term "Southern" covers a wide range of irons, from very good to very bad. By making the proper selection of Southern iron and using it with the proper Pennsylvania, New Jersey, or Virginia irons, we can obtain some of our most desirable mixtures. But if we don't have the right combination we are bound to get bad results. The Southern irons are good irons in their way; that is, they have certain characteristics which unite with the characteristics of other irons to form excellent mixtures.

Mr. NOYES. On the program for last evening it was arranged that there should be a paper by Mr. Brackett on "Protective coatings for cast-iron pipe." Mr. Brackett is not here to-day, and I do not know whether he will be here to read his paper or not, but as we have practical foundry men of large experience present, I would like to ask a question touching on the subject which might, perhaps, more properly have been discussed after the reading of Mr. Brackett's paper. As Mr. Prince has said, many of our specifications are made up by cutting from other specifications, and doubtless we have been inclined to follow on certain subjects the older engineers of repute, and who, we assume, have formed their opinions from study and experience, forgetting that perhaps they may have taken their ideas from the previous practice and have said that what was good enough in the past was good enough for them. Now in the specifications for cast-iron pipe the process for coating is generally described in detail. I know that in certain foundries where I have been it has been found desirable to depart more or less from the description, and in fact I have been told that it was not followed at all. I believe very strongly that as engineers, or as water works men, we should endeavor to draw our specifications so as to call for just exactly what we want and for what is the best; and I believe that to a certain extent we can work in conjunction with the parties who are to produce the goods our specifications call for so as to get the very best results both in the way of price and in the way of goods. Possibly Mr. Prince would be willing to tell us something with regard to their experience in the coating of cast-iron pipe.

Mr. PRINCE. I am very sorry Mr. Brackett is not here, because I know he has devoted a good deal of time to this subject, and could give us valuable information in regard to it. I will simply say that the process of Dr. Angus Smith, that is to say, the mixture of coal tar, oil, and one or two other ingredients, is not used at all now. In the first place the coal tar of to-day is very different from the coal tar of fifty years ago. The process of making it is different, and the products from different gas works to-day vary largely in their chemical constituents, depending upon the different processes that are used. Dr. Smith's process called for putting a cold pipe in the heated tar and keeping it there for half an hour until the pipe got thoroughly warm. With our present out-put it would be impossible for us to do that. So we first heat the pipes to the proper temperature and then immerse them for about five minutes in the tar. If we had to let them stay there half an hour before we took them out we could n't begin to get through our day's work. Of course, the pipes are tested to see that they are at the proper temperature before they are put in; then they are dipped and allowed to remain for a few minutes, and then are withdrawn and drained and put on the skids. We use the clear coal tar. I think the mixture of linseed oil amounts to very little, because the warm pipe when it is taken out very soon dries out the oil which is in the mixture, so that while theoretically it gives a good result, practically the oil is all dried out by the warmth of the pipe after taking it from the bath, and you have only what you started with, the coal tar coating. Does that answer your question, Mr. Noyes?

Mr. NOYES. I think it does. There is one other question which possibly some one here can answer, and that is as to the lasting qualities, or rather as to the protective qualities, of the Angus Smith coating as compared with the coatings we get now.

Mr. GARRETT. I think that could be proven by the record, if the information were really available, as to whether the pipe was treated with the Angus Smith process.

The PRESIDENT. I want to say that this discussion is extremely interesting, and I dislike to bring it to a close; but there is something due to those members who have prepared papers, and I think in justice to them, we should now close this discussion, and proceed with the other papers.

THE FINANCIAL MANAGEMENT OF WATER WORKS.

BY FREEMAN C. COFFIN, BOSTON, MASS.

Read June 10, 1896.

The questions involved in the financial management of water works are of interest and importance second only to those of successful construction. This paper will deal only with municipal works; they are more open to investigation and study than are those owned by private companies, and their finances are more a matter of public interest.

Shortly after beginning to collect the statistics for this paper, the writer was appointed one of a committee of this Association to report upon certain aspects of the financial condition of Municipal Water Works. I was requested by the chairman of that committee to make some report in connection with this paper. This I have endeavored to do as well as possible with the material available. This has modified the character and scope of the paper, which was at first intended to be a study of statistics of operation, and only incidentally with regard to their bearing on the financial success of the works.

Some questions were raised by a guest of this Association at the annual convention in June, 1894, that were of importance and led directly to the appointment of the committee referred to. The questions were in substance as follows: —

First. Are municipal water works systems self-supporting, or will the annual receipts meet the annual expenditures for maintenance, interest, and depreciation?

Second. Are water rates sometimes lowered to a point that renders the works incapable of producing enough revenue to meet the expenditures?

Third. Is the bonded indebtedness expanded for purposes other than that of legitimate construction?

Fourth. Should not extensions of pipe lines and laying of services and similar construction be classed as maintenance and be paid for from the yearly revenue, such being the policy of private companies?

Fifth. As an inference from the foregoing questions, are water rates generally as high as they should be?

An analysis of these questions is necessary. Some points must be settled and some definitions made before the subject can be intelligently discussed.

At the outset of this study, we are met with the fact that there seems to be no generally accepted system of financial management of water works, or even any well defined and generally accepted principles upon which such a system might be founded. Custom and practice vary in different places, and individual works apparently have no consistent theory of procedure. It is hard, if not impossible, to extract required information on important points from the reports of many works.*

In what follows an endeavor will be made to show the need of a consistent and generally accepted theory of management, and in a tentative and preliminary manner to define the terms or nomenclature of water works management.

MAINTENANCE.

In no branch of the subject are settled principles or careful definitions more needed than here. When a report is studied, there should be a fairly clear understanding of what is included under this head, and a settled agreement as to which items of expense are to be classed as maintenance and which as construction, such as does not now exist.

The greatest confusion and uncertainty seem to arise in the treatment of extensions of pipe lines and services. In some reports a part of the services are charged to maintenance and part to construction; in one case about twenty-five and seventy-five per cent respectively.

It has been claimed that as private companies make a practice of paying for ordinary extensions from current receipts, that properly managed municipal works should do the same. In one respect the management of private is different from that of municipal works. I believe that it is not generally the custom among private works to set aside a yearly sum for the depreciation of the plant, while it is the rule that municipal works do this, or cover the same ground in

*Those works which have adopted the form of statistics approved by this Association are a striking exception to this statement, and it is to be regretted that more do not avail themselves of this excellent form.

their provision of a sinking fund. This is a condition of the charters under which their bonds are issued. An examination of this subject of a sinking fund and the depreciation of plant may serve to clear up somewhat this question of maintenance and construction.

DEPRECIATION AND A SINKING FUND.

If a system adds to its construction account each year and makes no provision for the payment of the principle, or for the depreciation of the plant, it would at some future time find itself loaded with a debt and with a worn-out plant on its hands. If it is to go on with its business of supplying water, it must, on account of the deterioration of its plant or the abandonment of some of the same owing to improvements in machinery and other appurtenances of water works construction, incur large expenditures. Such a course would mean final insolvency or a large and sudden demand on the taxpayers. It is claimed by some that to avoid this result, all *ordinary* extension and construction should be classed as maintenance and be paid from current receipts; that nothing but large or unusual expenditures for construction should be met by the issue of bonds. As it is a general principle that is sought, and as there is no way to definitely draw the line between ordinary and large or unusual construction, a method that leaves to arbitrary judgment the apportionment of such expenditure is unsatisfactory.

When a sum is set aside from the revenue each year that, with its accrued interest, is amply sufficient at the end of the life of the works to rebuild or renew them, all legitimate construction may be paid for by the issue of bonds with the provision that for all such construction is provided a sum to cover its depreciation. In this way the finances of a system are kept in equilibrium. The present is not incurring liabilities for the future to pay, and providing no assets for it to realize upon, nor burdening itself by striving to pay for construction that will benefit the future. Each year or period of years will pay its own bills and leave the future years to do the same. There can hardly be injustice in this if construction is not unwisely undertaken.

This system will never place the works out of debt in the sense of paying up all of the bonds, but the point now made is that it is not necessary to good, solvent, business management to do so if there are always assets on hand equal to the liabilities. This provision for de-

preciation should not be confounded with a sinking fund, although the creation of such a fund usually provides for the former. A sinking fund primarily provides a fund for the payment of the bonds at a certain time. It is not clear whether or not a consideration of the depreciation of the plant originally entered into this provision.

The sinking fund period may or may not be identical with the life of the plant. As a matter of fact, I believe the maturity of the bonds rarely extends beyond thirty years. Two per cent of the cost set aside each year will, with accrued interest at three and one third per cent per annum, meet the total cost in thirty years. I believe that one and one half per cent of the cost paid each year with the interest will amply cover the depreciation. This percentage with interest at three per cent will equal the cost in thirty-seven years; at three and one half per cent in thirty-five years, and this period can hardly be considered excessive for the average life of a well built plant if it is kept in fair repair. This percentage for depreciation (if correct) should be the one used when it is desired to find the total annual expenditure that must be met from the revenues when the works are run on a business basis.

If the annual contribution to the sinking fund is such that the sinking fund will equal the cost of the works in a shorter period than the average life of the plant, the difference is an asset of the system uncovered by liabilities, and the extra amount can well be paid by taxation if necessary. If one and one half per cent is a fair estimate for depreciation, and two per cent is paid into the sinking fund, the value of this asset at the time the bonds are paid is one fourth of their face, or one fourth the cost of the works.

The foregoing is not an argument against paying for extensions or other construction from current funds if possible; that is certainly desirable, but it is not necessary to sound business management or to the solvency of the works to do so, and it may be doubtful if it is good policy to increase water rates for that purpose.

In order to definitely and finally settle the distinction between construction and maintenance we must go back to some fundamental principle. This principle is suggested by the words themselves. Construction implies new work, something created; labor and material applied to the production of something that did not previously exist in that form or place. It would include all expenditure for increasing or improving the plant in order to secure new sources of

revenue; also all renewals of worn-out or superseded parts of the plant. It would not include repairs, care, or minor improvements to existing structures.

Maintenance implies all expense connected with operating and maintaining the works; keeping all parts of the same in good order and condition so far as this can be done by repairs. Repairs would include renewals of minor parts of a structure, but not a renewal of the structure itself; for instance, the replacing of a broken pipe, but not the relaying of a street line.

It includes all expenditure on the plant necessary to keep it in good condition, to meet the demands from its present sources of revenue, but not for enlargements or additions to secure more revenue; nor does it include the renewals of parts that are worn out or superseded; the latter are provided for by the sum set aside for depreciation.

The operation of the above principle would classify some items as follows: —

Maintenance. Salaries of permanent officials and employees; care and repairs of plant; pumping expenses; the expense of the above, with a proper amount for interest and depreciation of the plant, would constitute the total annual expenditure for its operation, and should be met from the annual revenue and not by the sale of bonds.

Construction. New pipe lines; new services; new or additional water supplies; improvements of supplies, such as filtration plants, clearing mud from basins, draining swamps, etc.; new buildings and machinery, reservoirs, and stand-pipes; renewals on account of deterioration or insufficiency. Sound business management does not require that such items as the above should be paid from the current revenue.

REVENUE.

A clear definition of what constitutes the legitimate revenue of a municipal system of water works is of importance equal to that of maintenance. All receipts for water service from private consumers are beyond question part of the revenue. Is the money appropriated by the municipality for water for public buildings, fountains, street sprinkling, etc., and for hydrant service for fire protection, a legitimate part of the revenue? If so, what relation should the amount bear to the total expenditure, in order that it shall be only a fair

return for service rendered, and not an unjust burden laid upon the taxpayers that the rates may be low for the benefit of the consumer? The fact must be recognized that the taxpayers and consumers are not identical.

The answer to the question of the equity of a charge for fire protection, and of the proportion of such charge to the total expenditure may be suggested by an examination of the effects of the provision for such protection upon the cost of construction and maintenance. The provision for adequate fire protection materially increases the cost of construction over that necessary for domestic and manufacturing purposes alone. Although the yearly consumption of water for fire protection is but a small percentage of the total, it must be supplied in large quantities in a short time. This requires that the pipes and machinery shall be of greater capacity and the distributing reservoir larger than for domestic service alone.

The increase of cost may be roughly estimated as follows:—

INCREASE IN COST OF CONSTRUCTION FOR FIRE PROTECTION.

For quantity of supply	0
" quality " "	0
Pumping Machinery	100 per cent.
" Stations	33 " "
Pipe System	100 " "
Reservoir or Standpipe	75 " "

Making an average increase in cost of construction of perhaps 75 per cent.

INCREASE IN COST OF MAINTENANCE.

Care and repairs of Pipe System	100 per cent.
Pumping Expenses	33 " "
Office	0
Interest and depreciation	75 " "

Or an increase in the total annual expenditure of probably 50 to 75 per cent; making the additional expenditure due to provision for fire protection from 33 to 43 per cent of the total. This estimate can hardly be considered excessive. Mr. J. Herbert Shedd, a member of this Association, places the proportion at 50 per cent.* As the

*See discussion of J. R. Freeman's paper on "Fire Streams," in the Journal of N. E. W. W. Association of March, 1890.

benefits arising from this fire protection inure to the taxpayers and not to the water consumers, it is only just that at least the additional expense caused by it should be borne by the former.

Viewing the subject from another standpoint, when the system is owned by a private company, a hydrant rental is usually paid by the municipality and raised by taxation. This rental will probably average not less than thirty dollars per hydrant per annum. A price per hydrant is not a correct measure of the value of fire service unless the number of hydrants is also considered. The piping system would necessarily be of as great capacity (and should be greater) when the hydrants are far apart as when they are near together. Perhaps a more correct basis would be so much per hydrant and so many hydrants per mile of pipe. The present practice is to place hydrants too far apart. Viewed from a financial standpoint this is poor policy, especially where the municipality owns the works. It necessitates the use of long lines of hose, greatly decreasing the efficiency of the works.

Undoubtedly the increased expenditure in construction caused by a generous number of hydrants will increase the real efficiency of the system for fire protection much more than the same expenditure in any other direction. It must be remembered that the ideal system would be one in which the static head and the dynamic head at the nozzle were the same, and the best designed works are those that come nearest to this ideal. It should be the constant endeavor in designing a distribution system to secure a proper efficiency at the nozzle with the least possible static head, ever mindful that the interest and depreciation on the increased cost of construction must not exceed the amount saved in running expenses. The economic ideal of design is that in any contemplated improvement the interest and depreciation shall about equal the saving in operating expenses. Sometimes, unfortunately, all question of permanent economy must give way to a necessity for small first cost.

Suppose a street three thousand feet long with six hydrants placed six hundred feet apart on a six-inch main fed from both ends. Four fire streams of two hundred gallons each are needed at a building about midway between two hydrants. Not less than three hundred feet of hose would be required for each stream. If five more hydrants were placed upon this line, reducing the distance apart to three hundred feet, one hundred and fifty feet of hose would answer

equally as well as three hundred in the first instance. The loss of head by friction in the hose would be reduced thirty-one feet, while the cost of the five hydrants would be about $250. This would be partially offset by the saving of wear in six hundred feet of hose dispensed with; on the other hand, if the size of the pipe were increased to eight inches, and the hydrants remain as at first, the loss of head would be reduced about twenty feet, and the increased cost would be about $650; or by doubling the number of hydrants, thirty-one feet head would be saved at a cost of $250 or less; by increasing the size of the pipe from six to eight inches, twenty feet head would be saved at a cost of $650.

To return to the subject of revenue. In view of the foregoing, if in any system the amount appropriated by the municipality for fire service does not exceed fifty per cent of the total annual expenditure including interest and depreciation, the taxpayers are not contributing more than is just toward the support of the works, considering that to supply the consumers alone but from fifty-seven to sixty-seven per cent of the total would be required, while to give fire protection alone, probably not less than that percentage would be needed. It may also be said that if the amount appropriated for fire protection did not exceed $30 per hydrant, it would not be excessive, although this is not so correct a standard, owing to the great variation in the number of hydrants per mile in different places. This reasoning is based upon the assumption that the fire service is such as would be considered by competent authority an efficient one for the place in question.

WATER FOR PUBLIC PURPOSES.

There is one more legitimate source of revenue: this is for the water used in public buildings for ornamental and drinking fountains, street sprinkling, and for flushing sewers. In regard to the quantity used for these purposes, I will quote as follows from a paper read before the American Society of Civil Engineers in June, 1895, by Mr. Dexter Brackett, a member of this Association: "The quantity of water used for these purposes varies to a great extent in different cities on account of the difference in the method of supply. In some cases no charge is made for water for public purposes, while in others the water is supplied through meters, and the water depart-

ment is paid for all water used. Where no charge is made, the consumption is apt to be excessive. . . . A careful study of the quantity required for different public uses based upon such information as the author has been able to obtain, gives the following requirements for the different purposes: —

	Gallons per capita.
Public Buildings, Schools, and Hospitals	2.30
Street Sprinkling	1.00
Flushing sewers and public urinals	.10
Ornamental and drinking fountains	.25
Fires	.10
Total for public purposes	3.75

"Probably four or five gallons per capita should cover all requirements for public purposes."

In making an estimate for general application it would not be excessive to allow three gallons per capita for all public purposes except fires, and from fifteen to twenty cents per thousand gallons would not be too high a price, as will be shown later in this paper.

It follows then, that there are three main sources of revenue: —

First. Rates paid by all classes of private consumers.

Second. Revenue received for water for public purposes.

Third. Appropriation for fire protection.

If in any system the aggregate receipts from these sources equals or exceeds the total annual expenditure, including interest on the cost and a proper sum for depreciation, the works are self-supporting, and may be said to be run upon business principles, with no discrimination in favor of either consumer or taxpayer.

WATER RATES.

We now come to the question whether water rates as generally levied in municipal works are high enough to render the works self-supporting. The answer to this question may be found, or at least suggested by the application of the principles set forth in this paper. An endeavor is made to do this in the case of a number of works, mostly in New England. Table B gives the results in these works. At this point I will state briefly the plan of tabulation of the sta-

WATER WORKS STATISTICS.

TABLE A.

PUMPING.

NUMBER GIVEN TO COLUMNS:			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
														POPULATION.		HEAD.	
Date of Report.	List Number.	CITY OR TOWN.	Total Cost of Works.	Miles of Pipe.	Number of Services.	Average Duty.	Annual Consumption in Gallons.	Pounds of Coal.	Pumping Station Expenses.	Maintenance Exclusive of Interest.	Total Revenue from Rates.	Number of Hydrants.	Appropriation.	Total Inhabitants.	On Pipe Line or Consumers.	Static.	Dynamic.
1893	1	Avon, Mass.	$53,945	5	248	15,750,000	20,300,000	197,000	$1,614	$1,817	$3,681	49	$1,000	1,450	1,000	168	183
1894	2	Geneseo, N. Y.	81,500	12	300	6,600,000	46,800,000	700,000	600	3,218	4,145		2,450	2,700	1,750	100	120
1894	3	Needham, Mass.	142,160	22.06	493		40,959,255	325,159	1,600	2,717	4,552	178	5,000	3,900	2,550	223	245
1893	4	Mansfield, Mass.	79,250	8	343		76,338,900	400,317	1,900	2,100	5,349	88	1,500	3,700	2,800	154	
1894	5	Maynard, Mass.	109,000	7.75	465	25,000,000	37,000,000	250,000	745	1,320	4,230	77	2,000	3,000	2,800	186	206
1894	6	Wellesley, Mass.	229,090	25.30	647	39,600,000	67,923,480	393,541	1,538	4,510	8,514	200	3,300	4,000	3,467	250	278
1893	7	Reading, Mass.	174,800	18.40	600	36,200,000	80,875,000	426,000	2,707	4,149	5,283	103	5,600	4,200	3,600	219	236
1894	8	Turners Falls, Mass.	109,910	9	371		117,736,202	586,138	2,500	4,110	9,202	55	3,000	4,500	3,700		225
1894	9	Middleboro, Mass.	102,464	13.50	673	27,729,407	78,174,000	482,330	2,580	3,925	9,924	99	2,000	6,700	4,000	172	205
1890	10	Ware, Mass.	88,835	8.45	430	33,250,027	58,880,010	360,356	1,593	2,592	5,810	80	1,380	7,315	4,500	221	244
1893	11	Whitman, Mass.	111,318	14	751	15,000,000	69,092,000	675,000	2,000	3,480	7,100	130	2,450	6,000	4,600	146	170
1894	12	Canton, Mass.	188,000	18.54	650		60,851,929	373,050	2,534	3,400	6,287	152		4,700			
1894	13	Andover, Mass.	182,000	23.50	655	56,000,000	117,000,000	515,000	2,500	3,900	8,400	178		6,200	4,800	196	300
1894	14	Marblehead, Mass.	262,553	25.50	1,156	18,400,000	79,428,000	627,723	3,500	4,390	11,500	266		8,200	5,000	168	175
1893	15	Randolph and Holbrook, Mass.	280,000				106,000,000	654,263		6,538	8,930		4,500	5,992	5,700		280
1894	16	Attleboro, Mass.	276,541	28.28	1,000	34,385,136	99,136,440	452,050	1,860	5,191	10,352	170	3,900	8,000	6,500	160	188
1893	17	Natick, Mass.	259,243	29 85	1,486	53,896,985	127,238,184	345,300	2,382	7,477	19,750	161		9,000	6,500	167	175
	18	Dedham, Mass.*	206,317	25	905	32,282,983	110,749,322	477,350		7,558	20,377	131		8,000		146	165
1893	19	Peabody, Mass.	313,500	30	1,625	20,000,000	277,500,000	742,000	2,915	5,751	21,000				10,000		
1893	20	Marlboro, Mass.	294,000	33	2,080	49,400,000	160,600,000	526,000	2,026	6,325	28,000	389		14,000	10,000	190	204
1893	21	Charlottetown, P. E. I.	201,266	18	1,761	27,400,000	125,522,000	585,000	1,680	3,538	12,758	92		13,000	12,000	140	153
1893	22	Woburn, Mass.	571,330	49.25	2,464		337,916,250	1,243,100	6,335	12,630	32,485	313	2,700	14,000	13,300		206
1893	23	Quincy, Mass.	677,000	44.84	1,889	44,476,000	266,264,100	1,018,492	5,068	11,370	32,260	186	4,400	20,000	14,000	205	210
1894	24	Brookline, Mass.	1,204,825	60.2	2,549		555,783,793	1,293,277	11,530	18,000	49,121	383	15,773	15,154	15,000		190†

1894	25	Burlington, Vt.	450,092	34.91	2,835		336,504,725		7,940	31,867	38,225	187	3,330	15,700	15,100	270	316
1893	26	Waltham, Mass.	519,000	45.90	2,920	40,663,230	385,073,400	1,500 600	8,359	28,796	56,940	250	4,043	21,000	20,000	164	190
1894	27	Schenectady, N. Y.	220,000	23.50	2,732		1,742,504,000	4,638,000	15,047	26,750	42 810	242		22,000	21,000	146	203
1893	28	Taunton, Mass.	981,845	69	3,635	50,000,000	387,375,000	920,000	6,799	15,254	48,530	658	6,000	27,000	23,350		150
1893	29	Brockton, Mass.	612,700	48.82	3,650	26,957,683	252,780,531	469,222	2,773	6,912	36,352	421	3,000	30,000	24,000		135
1894	30	Woonsocket, R. I.	555,539	37.80	1,621	50,000,000	206,107,000	834,594	3,440	10,086	30,222	436	13,525	27,000	25,000	241	243
1892	31	Newton, Mass.	1,655,364	105	5,002	63,800,000	463,686,489	1,423,200	6,209	14,887	69,118	704	18,297	29,000	26,500	231	260
1894	32	Salem, Mass.	1,784,396	60	5,960	60,400,000	840,721,052	1,938,330	11,283	32,037	57,920	405		32,000	31,500		133
1894	33	Yonkers, N. Y.	1,297,444	50	3,500	50,000,000	992,000,000	4,017,200	15,590	30,934	98,963	513	15,390	36,000	32,000	196	220
1894	34	New Bedford, Mass.	1,590,121	63.80	7,531	70,000,000	1,810,400,000	2,560,000	13,466	31,122	85,000	585	12,000	45,000	44,150	125	130
1894	35	Lawrence, Mass.	2,151,990	65.24	5,056	104,595,585	1 049,938,320	1,624,900	9,353	31,376	85,863	538		48,500	48,000		185
1893	36	Pawtucket, R. I.	1,674,750	118 50	6,386	110,000,000	1,732,825,000	3,600,000	16,525	43,000	129,561	867	14,920		60,000		275
	37	Lynn, Mass.	2,096,350	120	11,095	99,736,937	1,306,471,699	1,769,550	9,843	38,707	174,937	895	20,000	69,650	66,850	159	161
1893	38	Fall River, Mass.	2,176,641	74	6,138	46,000,000	889,954,187	2,994,880	11,560	44,796	119,264	743	13,500	89,576	81,000		186
1893	39	Cambridge, Mass.	3,525,993	123	12,182	51,000,000	2,127,878,627	3,246,200	14,055	53,000	250,032	834		85,000	85,000	91	93

GRAVITY AND PUMPING.

	40	Plymouth, Mass.	248,214	33	1,543		103,475,400	229,000		5,587	17,830	87		7,500		65	66
	41	Malden, Mass.	742,434	67.6	4,750		400,000,000		8,491	31,619	75,000			24,000			
1893	42	Haverhill, Mass.	826,809	45.8	3,772		1,110,000,000	833,000		10,380	81,980	199		31;000	26,000		

GRAVITY.

1894	43	Hudson, Mass.	115,000	16	751					900	8,350	119	1,000	4,800	3,500		
1894	44	Wallingford, Conn.	184,000	19						2,500	12,000	78			5,000		
1893	45	Westboro, Mass.	165,000	13.25	673					700	8,000	81	810	5,000			
1893	46	Northampton, Mass.	305,345	45.75	2,000					2,692	27,337	231	2,000	16,400	12,000		
1894	47	New London, Conn.	554,864	41.50	2,556		426,941,118			6,944	34,907	193	9,650	14,700	14,500		
1893	48	Fitchburg, Mass.	940,000	55	3,571					23,111	54,500	359		25,000	25,000		
1893	49	Holyoke, Mass.	681,217	49	2,974					4,168	68,694	364	3,000		40,000		
1893	50	Manchester, N. H.**	1,150,000	73	4,169					33,000	90,900	568	12,750	50,000	40,000		
1893	51	St. John, N. B.	1,327,421	62.45	5,160					17,000	91,000				40,775		
1893	52	Springfield, Mass.	1,660,140	64.70	7,000		1,576,000,000			35,000	160,936	691	19,178	50,526	43,000		

NOTE. — Systems are tabulated according to the number of consumers, beginning with the smallest.

* Owned by a Company. † Average head of high and low service. ** Pumping by Water Power.

TABLE B.

List Number.	EXPENDITURE.						REVENUE.					RAISED BY TAXATION.				
	8	16	17	18	19	20	9	21	22	23	24	25	10	26	27	28
	Cost of Annual Maintenance.	Interest on Cost of Work at 4 per cent.	Depreciation, 1½ per cent on Total Cost of Works.	Total Annual Expenditure.	Annual Expenditure per Consumer.	Cost per 1,000 Gallons based upon Total Annual Expenditure.	Revenue from Water Rates.	Revenue from Public Use based on 3 Gals. per Capita and 15 cents per 1,000 Gals.	Total Revenue from public and private Consumers.	Annual Revenue per Consumer.	Revenue per 1,000 Gallons Pumped.	Total.	Number of Hydrants.	Amount per Hydrant.	Per cent of Taxation to Total Expenditure.	Cost of Construction per Consumer.
1	$1,817	$2,158	$809	$4,784	$4 78	$0.236	$3,681	$165	$3,846	$3 84	$0.190	$938	49	$19 10	19.6	$54 00
2	3,218	3,260	1,223	7,701	4 30	.165	4,145	288	4,433	2 53	.094	3,268			42.4	46 30
3	2,717	5,686	2,132	10,535	4 13	.257	4,552	420	4,972	1 95	.122	5,565	178	31 30	52.8	55 40
4	2,100	3,170	1,189	6,459	2 31	.085	5,349	460	5,809	2 07	.076	651	88	7 40	10.1	28 30
5	1,320	4,360	1,635	7,315	2 60	.198	4,230	462	4,692	1 67	.127	2,623	77	32 70	34.5	39 00
6	4,510	9,163	3,438	17,111	4 93	.252	8,514	571	9,085	2 62	.136	8,026	200	40 10	47	66 10
7	4,149	6,992	2,622	13,763	3 82	.169	5,283	594	5,877	1 63	.073	7,886	103	76 50	57.3	48 50
8	4,110	4,396	1,648	10,154	2 75	.086	9,202	607	9,809	2 64	.084	341	55	6 20	3.4	29 70
9	3,925	4,099	1,537	9,561	2 39	.122	9,925	660	10,585	2 60	.136		99			26 60
10	2,592	3,553	1,332	7,477	1 66	.127	5,810	740	6,550	1 45	.111	932	80	11 60	12.5	19 70
11	3,480	4,453	1,670	9,603	2 09	.139	7,100	759	7,859	1 71	.114	1,744	130	13 40	18.2	24 20
12	3,400	7,520	2,820	13,740	2 93	.226	6,287	770	7,057		.116	6,683	152	44 00	48.6	44 80
13	3,900	7,280	2,730	13,910	2 90	.119	8,400	792	9,192	1 91	.079	4,718	178	26 50	34	37 90
14	4,390	10,500	3,938	18,828	3 77	.237	11,500	825	12,325	2 47	.156	6,503	266	24 50	34.6	52 50
15	6,538	11,200	4,200	21,938	4 00	.213	8,930	900	9,830	1 79	.093	12,108			55.4	46 50
16	5,191	11,067	4,148	20,401	3 24	.206	10,352	1,070	11,422	1 76	.115	8,979	170	52 70	44	42 30
17	7,477	10,370	3,888	21,735	3 34	.171	19,750	1,065	20 815	3 20	.164	902	161	5 60	4.1	40 00
18	7,558	8,253	3,095	18,906	2 36	.171	20,377	1,310	21,687		.196		131			29 60
19	5,751	12,540	4,702	22,993	2 29	.083	21,000	1,640	22,640	2 26	.082	353			1	31 35
20	6,325	11,760	4,410	22,495	2 25	.140	28,000	1,650	29,650	2 96	.185		389			29 40
21	3,538	8,050	3,019	14,607	1 22	.117	12,758	2,000	14,758	1 23	.118		92			16 75
22	12,630	22,853	8,570	44,053	3 30	.130	32,485	2,180	34,665	2 60	.102	9,335	313	29 90	21.2	43 00
23	11,371	27,080	10,155	48,606	3 47	.183	32,260	2,310	34,570	2 47	.129	14,036	186	75 60	28.9	48 40
24	18,000	48,193	18,072	84,265	5 62	.151	49,121	2,460	51,581	3 43	.093	32,699	383	85 50	38.8	80 40
25	31,867	18,004	6,751	56,622	3 69	.168	38,225	2,470	40,695	2 70	.121	15,922	187	85 20	28.2	29 90
26	28,796	20,760	7,785	57,341	2 86	.149	56,940	3,300	60,240	3 01	.156		250			25 90
27	26,750	8,800	3,300	38,850	1 85	.223	42,810	3,450	46,260	2 20	.265		242			10 50
28	15,254	39,274	14,727	69,255	2 98	.178	48,530	3,850	52,380	2 24	.135	16,875	658	25 70	24.4	35 40
29	6,912	24,508	9,190	40,610	1 69	.161	36,352	3,930	40,282	1 68	.150	330	491			

26	28,796	20,760	7,785	57,341	2 86	.149	56,940	3,300	60,240	3 01	.156		250			25 90
27	26,750	8,800	3,300	38,850	1 85	.223	42,810	3,450	46,260	2 20	.265		242			10 50
28	15,254	39,274	14,727	69,255	2 98	.178	48,530	3,850	52,380	2 24	.135	16,875	658	25 70	24.4	35 40
29	6,912	24,508	9,190	40,610	1 69	.161	36,352	3,930	40,282	1 68	.159	330	421	80	.8	25 50
30	10,086	22,221	8,333	40,640	1 63	.198	30,222	4,125	34,347	1 37	.167	6,293	436	14 40	15.5	22 15
31	14,887	66,215	24,830	105,932	4 00	.229	69,118	4,360	73,478	2 77	.158	31,454	704	44 70	29.7	62 50
32	32,037	71,370	26,765	130,172	4 14	.157	57,920	5,170	63,090	2 00	.075	67,091	405	166 00	51	56 70
33	30,934	51,898	19,462	102,294	3 20	.103	98,963	5,280	104,243	3 27	.105		513			40 50
34	31,122	63,605	23,851	118,578	2 69	.065	85,000	7,290	92,290	2 07	.051	26,288	585	45 00	22.2	36 00
35	31,376	86,079	32,280	149,735	3 08	.143	85,863	7,950	93,813	1 95	.090	55,863	538	103 80	37.4	44 50
36	43,000	66,990	25,121	135,111	2 25	.078	129,561	9,900	139,461	2 32	.081		867			27 90
37	38,707	83,854	31,445	154,006	2 27	.118	174,937	11,150	185,087	2 77	.142					31 40
38	44,796	87,065	32,649	164,510	2 03	.185	119,264	13,350	132,614	1 64	.149	31,896	743	43 00	19.4	26 90
39	53,000	141,040	52,890	246,930	2 91	.116	250,032	14,000	264,032	3 11	.124		834			41 50
	Minimum				1 22	.065	Minimum			1 23	.073	Minimum,		80	.8	10 50
	Average				2 58	.115	Average			2 32	.124	Average		42 74	28.86	38 41
	Maximum				5 62	.257	Maximum			3 84	.265	Maximum,		166 00	57.3	80 40

GRAVITY AND PUMPING.

40	5,587	9,928	3,723	19,238	2 75	.186	17,830	1,150	18,980	2 71	.184	250	87	2 87	1.3	33 20
41	31,619	29,697	11,136	72,452	3 12	.181	75,000	3,940	78,940		.197		895			31 00
42	10,380	33,072	12,402	55,854	3 15	.051	81,980	4,260	86,240	3 31	.078		199			31 80

GRAVITY.

43	900	4,600	1,725	7,225	2 06		8,350	575	8,925	2 55			119			32 90
44	2,500	7,360	2,760	12,620	2 63		12,000	820	12,820	2 56			78			36 80
45	700	6,600	2,475	9,775	2 44		8,000	656	8,656	2 00		119	81	1 47	1.2	41 30
46	2,692	12,214	4,580	19,486	1 63		27,337	1,970	29,307	2 44			231			25 50
47	6,944	22,194	8,323	37,461	2 58	.088	34,907	2,380	37,287	2 57	.087	174	193	90	.5	38 20
48	23,111	37,600	14,100	74,811	2 99		54,500	4,100	58,600	2 34		16,211	359	45 20	21.7	37 60
49	4,168	27,249	10,218	41,635	1 04		68,694	6,560	75,254	1 88			364			17 00
50	33,000	46,000	17,250	96,255	2 40		90,900	6,560	97,460	2 43			568			28 80
51	17,000	53,097	19,911	90,008	2 21		91,000	6,690	97,690	2 45						32 50
52	35,000	66,406	24,902	126,308	2 94	.080	160,936	7,050	167,986	2 40	.106		691			38 60
	Minimum				1 04		Minimum			1 88		Minimum				17 00
	Average				2 29		Average			2 36		Average				32 92
	Maximum				2 99		Maximum			2 57		Maximum				41 30

tistics presented. There are four tables, A, B, C, and D. Table A is a tabulation of the statistics collected from the works under consideration. I should have gladly presented a longer list. These, however, were all that I could secure in the time that I could devote to it. It is difficult to obtain statistics of even limited range that truly give the facts sought, except by giving much time and labor to the work of collection. I believe that the list of works is fairly representative of systems in general, except of those of the large cities, which are not included.

The items contained in Table A are those that are most important in a study of the financial side of water works management. Tables B, C, and D are based upon the figures given in Table A. Table B being an attempt to place the systems studied upon a similar basis for comparison.

Under the head of maintenance, column No. 8 gives the actual annual cost of maintenance of the works as reported. Column No. 16 gives the annual interest. This interest is not the actual interest paid by the works, but is four per cent on the cost of construction. The actual interest paid would not be a fair basis of comparison, for in some cases the bonds are partially paid, and in some a higher rate is being paid on old bonds. Therefore as a correct basis of comparison, and also to give the true economic cost of operating the works, four per cent on the total cost of construction is used for the interest account.

Column No. 17 gives the sum for depreciation at the rate of one and a half per cent of the cost of construction. This was adopted, instead of the actual amount paid into the sinking fund, for reasons similar to those given in relation to the interest account.

Column No. 18 is the sum of the first three, and is intended to represent the total economic cost of running the works, or the total expenditure necessary to carry on the works and keep them in proper condition.

Under the head of Revenue, column No. 9 gives the actual revenue received from private consumers. Column No. 21 gives the amount that should be paid to the departments for water for public uses on the basis of a use of three gallons per capita and fifteen cents per thousand gallons. Column No. 22 is the sum of the first two, and is intended to represent the total legitimate revenue except that for fire protection. Under the head of taxation, column No. 25 gives

the difference between the sum of the revenue from public and private sources and the total expenditure, and when the latter is larger than the former, represents the amount to be raised by taxation, or the cost for fire protection.

The next two columns give the number of hydrants and the annual cost of each, based upon column No. 25.

Column No. 27 gives the percentage which the amount in column No. 25 or cost of fire protection is of the total expenditure. The last column of this table gives the cost of construction of the system, per consumer, and shows roughly that in those systems that raise the greatest per cent by taxation, the cost of construction per capita is the greatest.

An examination of Table B shows that out of fifty-two systems there are fourteen in which the revenue from private consumers is sufficient to meet the total annual expenditure. There are nineteen in which the sum of this revenue and that figured for public purposes will do the same. There are thirty-three in which the revenue from these two sources does not equal the expenditure, and the balance must be raised by taxation, amounting to from 0.8 to 57.3 per cent of the total. In four systems this exceeds fifty per cent.

These results may be considered an answer to the question "whether or not municipal water works are self-supporting," so far as it can be answered in this paper.

The answer to the question "whether rates are sufficiently high" is also implied in the above.

ADJUSTMENT OF RATES.

If the rates in any system are not satisfactory, being either too high or too low, the problem of their adjustment to the requirements of expenditure is one of which it may not be too much to say that no solution has been advanced that considers the conditions of the problem.

The same may be said of fixing rates for new works. The only method that the writer is cognizant of is that of comparison, and comparison of rates only, and not of conditions as well. To collect the schedules of several systems and construct rates from these without regard to such factors as cost of construction per capita, consumption of water per capita, cost of water per million or thousand

gallons, etc., is not a rational method, and gives no assurance that the revenue will be approximately equal to the requirements; yet many if not all rates are fixed in this way.

It is possible to estimate quite closely the probable expenditure, and in case of existing works this is known. Is there any method by which rates can be adjusted to meet this expenditure? In existing works past experience would be a guide; but in new works there is no such guide. There can hardly be a theory advanced for the adjustment of fixture rates. It is possible that with the sale of water by measurement, rates could be devised that would bear some relation to the revenue required. This would, however, be difficult and uncertain until more data upon the subject is available. It may be that the units of maintenance, revenue, and consumption in the tables may be of some service in this connection.

On Table B, under the head of maintenance, in column No. 19, is given the yearly cost per capita based upon the number of consumers. (By consumers is meant the persons living on the pipe line. This basis is used as being more nearly correct for purposes of comparison than that of the total population.) This annual cost per capita is perhaps the most scientific unit for comparing the yearly economic cost of water works. This unit of cost seems to have no law of relation to the number of consumers. It is, however, largely influenced by the cost of construction per capita, and in a less degree by the consumption of water per capita. The fixed charges of interest and depreciation are approximately seventy-five per cent of the total cost of maintaining water works; therefore the item of first cost is the controlling factor in the yearly expense account.

No certain deductions can be drawn from averages of these tables, but a consideration of the minima, the maxima, and the averages of the different units given may serve as a guide in estimating expenses, revenue, and consumption; they are given with all of the units of the tables.

The minimum of the yearly cost per capita in pumping systems is $1.22; the maximum is $5.62, and the average is $2.58.

Column No. 20 under maintenance in Table B gives the cost per thousand gallons of water based upon the total expenditure and total amount of water pumped. The minimum is $0.065; the average $0.115; and the maximum $0.257. This cost is for total

pumpage, and does not represent the cost of water that can be delivered and registered at the meters of consumers.

Mr. Dexter Brackett, in the paper already referred to, shows that in several systems, after making a liberal allowance for unmetered water, only from fifty to sixty-six per cent of the total pumpage is accounted for at the taps of consumers.

With the exception of the deduction that may be made for "slip" in the pump, which would hardly exceed ten per cent, Mr. Brackett ascribes the discrepancy to leakage from mains and services that does not appear on the surface of the ground. The writer of this paper has recently made a careful investigation of the consumption of water in a system where the recording instruments in use afforded an opportunity to discriminate between the leakage in mains and services and the draft at the taps, by studying the relation of the night flow to that of the day. Omitting the details of the study, the results were that in a section of the system supplied by pumping, a total pumpage of about 300,000 gallons per day was found to be made up of 225,000 gallons of leakage and 75,000 gallons of consumption. This supplied approximately 1,000 persons, or at the rate of 75 gallons per capita. A large portion of the leakage was located on a few streets. It was supposed, previous to the examination, that the draft was due to consumption, as no leakage was apparent on the surface. This is an extreme case, but it is likely that in many cases of supposed excessive consumption, a similar state of things exists.

Incidentally the above suggests the desirability of recording instruments on standpipes and reservoirs, and some means of measuring the draft in gravity systems, so that its amount and distribution throughout the day may be known. I believe more attention should be paid to the matter of leakage from the mains in places of large consumption.

If from various reasons not more than one half or two thirds of the water pumped can be measured to the consumers, the cost of 1,000 gallons delivered will be much higher than the cost of 1,000 gallons pumped. If, as shown by Table B the cost of all the water pumped is from $0.065 to $0.257 per 1,000 gallons and averages 0.115, and the cost delivered at the meter is from one and one half times to twice as great, the actual cost of salable water is in some places higher than the rate charged, unless part of the maintenance account is

charged to fire protection. These points should be considered in any question of rates.

An examination of Table B shows that if the principles suggested in this paper are approximately correct, there are very few works that require more revenue from rates after the proper sum is appropriated for fire protection. I believe, from the study I have been able to make, that with the exception of a few works, the rates are sufficiently high to run the works in the manner that they are now run.

Water rates should not be lowered without first making a careful study of the condition and capacity of the supply, also of the distribution system, and a thorough consideration of the needs of the future, and the possibility of present improvement of the works.

More attention must be given in the future to the quality of the supply. This will require additional expense for construction and maintenance. Sand filtration is now practicable, and should be adopted in the case of inferior supplies. The consumer is entitled to as pure water as can be obtained at any reasonable cost. There are supplies that are good for the greater part of the year, but for a short time at certain seasons are very disagreeable if not injurious. Some provision should be made for good water throughout the year by a temporary supply or temporary filtration, if the cause of the trouble cannot be removed.

Many distribution systems are inadequate to furnish a suitable fire protection. Some are believed to be all right simply because they have not yet had to meet conditions that may arise at any time, and because no intelligent study has been made of their efficiency. Probably the works are few of which it can be said that they need no improvements. Therefore it seems unlikely that rates in general can be lowered, and it may be necessary to raise them to meet expenditures due to the increasing cost of supplying water. The growth of population may meet this demand. But with this increase of population, the cost of procuring for it additional supplies will constantly become greater, as will also that of preserving the purity of present sources.

The Metropolitan supply for Boston and its suburbs is estimated to cost ninety cents per capita per annum for the entire population served. This is in addition to the present cost of supply and distribution. There is this to be said, however, if rates cannot be lowered, or even if they must be raised in some cases, that there is no other

service (unless it be the postal service) in which people receive so much that contributes to the necessities, the conveniences, and the luxury of living from the same expenditure, as they do from a well built, well managed system of public water works.

There are three lines of effort the necessity of which should be emphasized, and to advancement along which the influence of the members of this Association should be directed: —

First. Conserving the quantity of supplies by checking waste in all forms.

Second. Improving the quality of the water.

Third. Rendering thoroughly efficient the distribution systems.

Each of these has its bearing on the finances of the system. The first leads to a reduction of expense, and would sometimes prevent a large expenditure for additional supplies. The second and third tend in the opposite direction, and in some cases might necessitate higher rates.

TABLES C AND D.

I will briefly call attention to some of the units in these tables: —

Column 29 of Table C gives the consumption per capita based on the total population. Column 30 gives the same based on consumers, or the persons living on the pipe lines. The consumption per capita seems to follow a general law of increase with increasing population.

Diagram No. 1 shows the curve of average consumption per capita, based on the statistics of seventy-five places of from 1,000 to 1,000,000 consumers. The formula of this curve is 40 (total number of consumers, x .001) $^{.14}$.

This curve quite truly represents the average and runs from forty to one hundred and five gallons per capita. None of the other units on the table follow any discoverable law. They are as follows: —

Number of gallons pumped per pound of coal.

Number of gallons pumped one foot high per pound of coal.

Cost per million gallons based on pumping station expenses. Same pumped one foot high.

Cost per million gallons based on total maintenance exclusive of interest. Same pumped one foot high.

Population per mile of pipe and per service.

Annual cost of maintenance exclusive of interest and sinking fund, per inhabitant and per consumer.

TABLE C.

List Number.	CONSUMPTION.				PUMPING.						POPULATION.			
	Consumption in Gallons.	Coal used in Pounds.	Daily Consumption per Capita.		Gallons of Water Pumped per Lb. of Coal.		Cost per Million Gallons based on Pumping Station Expenses.		Cost Based on Total Maintenance per Million Gallons.		Population per Mile of Pipe.		Population per Service.	
			Inhabitants.	Consumers.	Total Head.	1 Ft. High Dynamic.	Total Head.	1 Ft. High Dynamic	Total Head.	1 Ft. High Dynamic	Inhabitants.	Consumers.	Inhabitants.	Consumers.
	5	6	29	30	31 = 5/6	32 = 31 × 15	33 = 7/6	37 = 33/15	35 = 8/5	36 = 35/15	37 = 1,2/2	38 = 1,3/2	39 = 1,2/3	40 = 1,3/4
1	20,300,000	197,000	38	56	103	18,900	$79 50	$0.433	$89 50	$0 488	290	200	5.85	4.03
2	46,800,000	700,000	48	73.5	67	8,040	12 80	.107	68 70	.572	225	146	9	5.8
3	40,959,255	325,159	29	44.2	126	30,900	39 00	.159	66 30	.271	177	113	7.8	5.2
4	76,338,900	400,317	56.7	74.6	191		24 90		27 90		462	350	10.8	8.2
5	37,000,000	250,000	34	36	147	30,400	20 10	.098	35 70	.173	387	362	6.5	6
6	67,923,000	393,541	47	54	173	48,100	22 60	.082	66 50	.239	158	137	6.2	5.4
7	80,875,000	426,000	53	62	190	44,700	33 40	.142	51 20	.217	228	196	7	6
8	117,736,202	586,138	71.8	87.4	201	45,250	21 20	.094	34 90	.155	500	412	12.1	10
9	78,174,000	482,330	32	54	162	33,300	33 00	.161	50 30	.245	496	296	10	6
10	58,880,010	360,356	22.1	36	163	39,772	27 10	.111	44 00	.181	865	532	17	10.5
11	69,092,000	675,000	32	41	102	17,400	29 00	.170	50 30	.295	428	328	7.9	6.1
12	60,851,929	373,050	36.5		164		41 60		55 90		254		7.2	
13	117,000,000	515,000	52	67	227	68,100	21 40	.071	33 30	.111	262	204	9.5	7.3
14	79,428,000	627,720	27	44	126.5	22,200	44 10	.252	55 40	.317	322	196	7.1	4.3
15	106,000,000	654,263	49	51	162	45,400			61 60	.220				
16	99,136,440	452,050	34	42	219	41,250	18 75	.100	52 40	.278	283	230	8	6.5
17	127,238,184	345,300	38.7	53.7	368	64,400	18 70	.107	58 75	.336	300	218	6.1	4.4
18	110,749,322	477,350	38		232	38,300			68 30	.414	320		8.9	
19	277,500,000	742,000		76	374		10 50		20 80			333		6.15
20	160,600,000	526,000	31	44	306	62,200	12 60	.062	39 40	.193	425	303	6.7	4.8
21	125,522,000	585,000	26	29	215	32,900	13 40	.087	28 20	.184	723	677	7.4	6.8
22	337,916,250	1,243,100	66	69.5	272	56,200	18 70	.091	37 50	.181	284	274	5.7	5.5
23	266,264,000	1,048,492	36.5	52	254	53,400	19 00	.091	42 70	.203	446	312	10.6	7.4
24	555,783,793	1,293,277	103.5	104 5	430	81,600	20 80	.11	32 40	.171	252	249	5.9	5.9
25	336,504,725		58.7	61			23 60	.075	95 00	.300	452	434	5.5	5.3
26	385,073,000	1,500,600	50	53	257	48,800	21 70	.114	74 80	.394	458	436	7.2	6.9
27	1,742,504,000	4,638,000	218	227	377	76,500	8 65	.043	15 35	.076	938	894	8.1	7.7
28	387,375,000	920,000	40	46	422	63,300	17 55	.117	39 50	.263	392	338	7.4	6.4
29	252,780,531	469,222	23.2	29	540	73,000	11 00	.073						
30	206,107,000													

24	555,783,793	1,293,277	103.5	104 5			23 60	.075	95 00	.300	452	434	7.2	6.9
			58.7	61										
25	336,504,725				257	48,800	21 70	.114	74 80	.394	458	436	7.2	7.7
26	385,073,000	1,500,600	50	53	377	76,500	8 65	.043	15 35	.076	938	894	8.1	
27	1,742,504,000	4,638,000	218	227										
28	387,375,000	920,000	40	46	422	63,300	17 55	.117	39 50	.263	392	338	7.4	6.4
29	252,780,531	469,222	23.2	29	540	73,000	11 00	.082	27 30	.203	615	492	8.2	6.6
30	206,107,000	834,594	21	23	247	60,000	16 70	.069	48 90	.201	715	662	16.6	15.4
31	463,686,000	1,423,200	47	48	326	84,700	13 40	.052	32 10	.124	257	252	5.4	5.3
32	840,721,052	1,938,330	71.8	73.1	434	57,600	13 40	.100	38 10	.297	534	526	5.4	5.3
33	992,000,000	4,017,200	76	85	248	54,700	15 70	.072	31 25	.142	720	642	10.3	9 2
34	1,810,400,000	2,560,000	110	112	707	92,000	7 44	.057	17 20	.132	705	692	6	5.9
35	1,049,938,320	1,624,900	59.4		648	120,000	8 90	.048	29 90	.162	744		9.6	
36	1,732,825,000	3,600,000		79	482	132,550	9 53	.035	24 80	.094		506		9.4
37	1,306,471,699	1,769,550	52	54	740	110,000	7 53	.467	29 70	.185	580	556	5	
38	889,954,000	2,994,880	27	30	297	55,200	13 00	.07	50 30	.275	1,210	1,090	14.5	13.2
39	2,127,878,600	3,246,200	69	69	656	61,000	6 60	.071	24 85	.267	690	690	7	7
	Minimum . . .		21	23	67	8,040	6 60	.043	15 35	.076	158	113	5	4.03
	Average . . .		52.02	62.30	299	56,344	21 00	.118	44 90	.238	475	411	8.32	6.9
	Maximum . . .		218	227	740	132,550	79 50	.467	89 50	.572	1,210	1,090	17	15.4

GRAVITY AND PUMPING.

40	103,475,400	229,000	38						$54 00		227		4.9	
41	400,000,000		46						79 20		355		5.1	
42	1,110,000,000	833,000	98	117					9 36		677	567	8.2	6.9

GRAVITY.

43											300	217	6.4	4.8
44												263		
45											377			7.4
46											359	262	8.2	6
47	426,941,118		79	81					16 30		352	350	5.8	5.7
48											455	455	7	7
49												817		13.5
50											685	548	12	9.6
51												665		7.9
52	1,576,000,000		85	100					22 20		785	665	7.2	6.1
	Minimum . . .										300	217	5.8	4.8
	Average . . .										473	472	7.75	7.56
	Maximum . . .										785	817	12	13.5

TABLE D.

List Number.	MAINTENANCE.						REVENUE.								
	Annual Cost of Maintenance.	Population.		Annual Cost of Maintenance.			Annual Revenue from Rates.	Annual Appropriation.	Total Revenue.	Revenue Per Inhabitant.		Revenue Per Consumer.		Revenue Per Service from Rates.	Revenue Per Million Gallons from Rates.
		Inhabitants.	Consumers.	Per Inhabitants.	Per Consumers.	Per Cent of First Cost.				From Rates.	Total Revenue.	From Rates.	Total Revenue.		
	8	12	13	41 = 8/12	42 = 8/13	43 = 8/1	9	11	44 = 9+11	45 = 9/12	46 = 11/12	47 = 9/13	48 = 11/13	49 = 9/8	50 = 9/6
1	$1,817	1,450	1,000	$1 25	$1 82	3.37	$3,681	$1,000	$4,681	$2 54	$3 23	$3 68	$4 68	$14 80	$181 50
2	3,218	2,700	1,750	1 19	1 84	3.95	4,145	2,450	6,595	1 53	2 44	2 36	3 78	13 80	88 60
3	2,717	3,900	2,550	70	1 07	1.92	4,552	5,000	9,552	1 17	2 45	1 78	3 75	9 25	111 00
4	2,100	3,700	2,800	58	75	2.65	5,349	1,500	6,849	1 45	1 85	1 91	2 44	15 56	70 00
5	1,320	3,000	2,800	44	47	1.21	4,230	2,000	6,230	1 41	2 07	1 51	2 22	9 10	114 20
6	4,510	4,000	3,467	1 13	1 30	1.98	8,514	3,300	11,814	2 13	2 96	2 46	3 41	13 17	125 50
7	4,149	4,200	3,600	99	1 15	2.37	5,283	5,600	10,883	1 26	2 59	1 47	3 02	8 82	65 30
8	4,110	4,500	3,700	92	1 11	3.75	9,202	3,000	12,202	2 04	2 72	2 48	3 31	24 80	78 00
9	3,925	6,700	4,000	59	98	3.8	9,925	2,000	11,924	1 48	1 78	2 48	2 98	14 75	127 00
10	2,592	7,315	4,500	36	58	2.93	5,810	1,380	7,190	80	99	1 29	1 60	13 50	98 50
11	3,480	6,000	4,600	58	76	3.13	7,100	2,450	9,550	1 18	1 59	1 54	2 07	9 39	102 60
12	3,400	4,700	4,200	73	81	1.81	6,287		6,287	1 34	1 34			9 68	103 00
13	3,900	6,200	4,800	63	81	2.14	8,400		8,400	1 35	1 35	1 75	1 75	12 83	71 80
14	4,340	8,200	5,000	54	88	1.67	11,500		11,500	1 40	1 40	2 30	2 30	9 97	145 00
15	6,538	5,992	5,700	1 10	1 15		8,930	4,500	13,430	1 49	2 25	1 72	2 36		84 30
16	5,191	8,000	6,500	65	80	1.88	10,352	3,900	14,252	1 30	1 78	1 59	2 20	10 32	104 50
17	7,477	9,000	6,500	84	1 15	2.9	19,750		19,750	2 19	2 19	3 04	3 04	13 30	155 00
18	7,558	8,000		95		3.67	20,377		20,377	2 55	2 55			22 50	184 00
19	5,751		10,000		58		21,000		21,000			2 10	2 10	12 92	75 67
20	6,325	14,000	10,000	45	63	2.15	28,000		28,000	2 00	2 00	2 80	2 80	13 45	174 50
21	3,538	13,000	12,000	27	30	1.76	12,758		12,758	98	98	1 06	1 06	7 25	102 00
22	12,630	14,000	13,300	91	95	2.22	32,485	2,700	35,185	2 32	2 51	2 45	2 64	13 15	96 00
23	11,370	20,000	14,000	57	81	1.68	32,260	4,400	36,660	1 61	1 83	2 30	2 62	17 05	121 00
24	18,000	15,154	15,000	1 19	1 20	1.5	49,121	15,773	64,894	3 24		3 27		19 25	88 50
25	31,867	15,700	15,100	2 03	2 11	7.1	38,225	3,330	41,555	2 44	2 64	2 54	2 75	13 50	114 00
26	28,796	21,000	20,000	1 37	1 44	5.54	56,940	4,043	60,983	2 71	2 90	2 84	3 05	19 50	147 80
27	26,753	22,000	21,000	1 21	1 27		42,810		42,810	1 95	1 95	2 04	2 04	15 70	24 60
28	15,254	27,000	23,350	57	66	1.55	48,530	6,000	54,530	1 80	2 02	2 08	2 34	13 36	125 40
29	6,912	30,000	24,000	23	29	1.13	36,352	3,000	39,352	1 21	1 31	1 51	1 64	9 95	143 70
30	10,086	27,000	25,000	38	41	1.82	30,222	12,525	42,747	1 12	1 58	1 21	1 71	9 25	143 70

25	31,867	15,700	15,100	2 03	2 11	7.1	56,225	3,000	59,225	2 71	2 90	2 84	3 05	19 50	147 80
26	28,796	21,000	20,000	1 37	1 44	5.54	56,940	4,043	60,983	2 71	2 90	2 84	3 05	19 50	147 80
27	26,753	22,000	21,000	1 21	1 27		42,810		42,810	1 95	1 95	2 04	2 04	15 70	24 60
28	15,264	27,000	29,350	57	66	1.55	48,530	6,000	54,530	1 80	2 02	2 08	2 34	13 36	125 40
29	6,912	30,000	24,000	23	29	1.13	36,352	3,000	39,352	1 21	1 31	1 51	1 64	9 95	143 70
30	10,086	27,000	25,000	38	41	1.82	30,222	13,525	43,743	1 12	1 62	1 21	1 75	18 65	146 50
31	14,887	27,000	26,500	55	56	.9	69,118	18,297	87,415	2 56	3 24	2 61	3 30	13 80	149 00
32	32,037	32,000	31,500	1 00	1 02	1.79	57,920		57,920	1 81	1 81	1 84	1 84	9 70	68 90
33	30,934	36,000	32,000	86	96	2.38	98,963	15,390	114,353	2 75	3 18	3 09	3 58	28 30	100 00
34	31,122	45,000	44,150	69	71	1.95	85,000	12,000	97,000	1 89	2 15	1 92	2 19	11 20	47 00
35	31,376	48,500	48,000	65	65	1.45	85,863		85,863	1 77	1 77			17 00	81 50
36	43,000		60,000		72	2.57	129,561	14,920	144,481			2 16	2 41	20 30	74 80
37	38,707	69,653	66,850	55	57		174,937	20,000	194,937	2 51	2 79	2 62	2 91	15 76	138 90
38	44,796	89,576	81,000	50	55	2.06	119,264	13,500	132,764	1 33	1 48	1 47	1 64	19 45	134 00
39	53,000	85,000	85,000	62	62	1.5	250,032		250,032	2 95	2 95	2 95	2 95	20 50	117 50
	Minimum			23	29	.9	Minimum			80	98	1 06	1 06	7 25	24 60
	Average			77	91	2.46	Average			1 83	2 13	2 17	2 59	11 98	109 31
	Maximum			2 03	2 11	7.1	Maximum			2 95	3 24	3 68	4 68	28 30	181 50

GRAVITY AND PUMPING.

40	5,587	7,500		75		2.25	17,830		17,830	2 38	2 38			11 50	173 00
41	31,619	24,000		1 32		4.16	75,000		75,000	3 12	3 12			15 80	187 00
42	10,380	31,000	26,000	33	40	1.26	81,980		81,980	2 64	2 64	3 15	3 15	21 70	73 70

GRAVITY.

43	900	4,800	3,500	19	26	.78	8,350	1,000	9,350	1 74	1 95	2 38	2 67	11 05	
44	2,500		5,000		50	1.36	12,000		12,000			2 40	2 40		
45	700	5,000		14		.42	8,000	810	8,810	1 60	1 76			11 90	
46	2,692	16,400	12,000	16	22	.85	27,337	2,000	29,337	1 67	1 79	2 27	2 44	13 60	
47	6,944	14,700	14,500	47	48	1.25	34,907	9,650	44,557	2 37	3 03	2 40	3 07	13 70	82 00
48	23,111	25,000	25,000	93	93	2.46	54,500		54,500	2 16	2 16	2 16	2 16	15 10	
49	4,168		40,000		10	.81	68,430	3,000	71,694			1 71	1 79	23 00	
50	33,000	50,000	40,000	66	83	2.87	90,900	12,750	103,650	1 81	2 07	2 27	2 59	21 80	
51	17,000		40,775		42	1.28	91,000		91,000			2 23	2 23	17 60	
52	35,000	50,526	43,000	64	82	2.1	160,936	19,178	180,114	3 19	3 56	3 75	4 19	23 00	102 00
	Minimum			14	10	.42	Minimum			1 60	1 76	1 71	1 79	11 05	
	Average			.455	.506	1.42	Average			2 08	2 33	2 40	2 62	16 75	
	Maximum			93	93	2.87	Maximum			3 19	3 56	3 75	4 19	23 00	

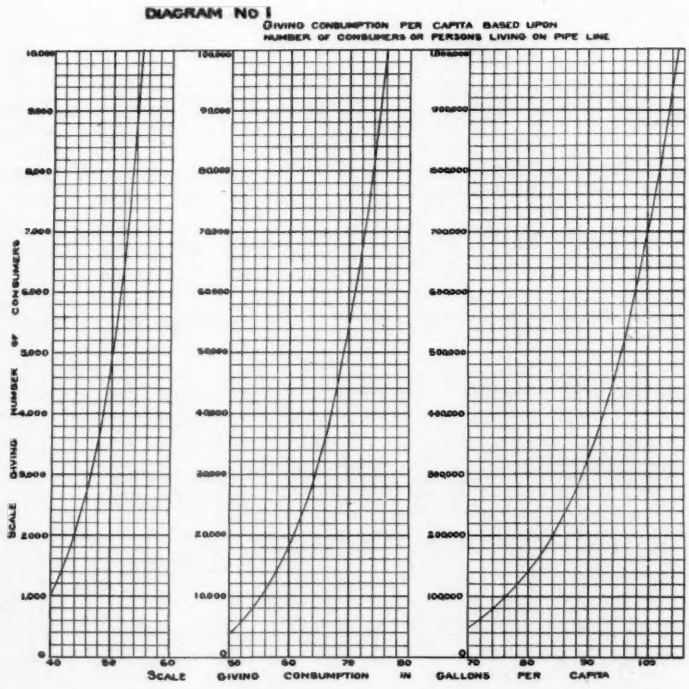


DIAGRAM NO I
GIVING CONSUMPTION PER CAPITA BASED UPON NUMBER OF CONSUMERS OR PERSONS LIVING ON PIPE LINE
SCALE GIVING NUMBER OF CONSUMERS
SCALE GIVING CONSUMPTION IN GALLONS PER CAPITA

Annual revenue per inhabitant based on receipts from rates, also on total receipts including appropriation. The same per consumer.

Revenue per million gallons based upon receipts from rates. The same per service.

The table gives the results for three classes of works: Pumping, Gravity and Pumping combined, and Gravity alone. These tables were computed with the slide rule, and in some cases the last figure may not be correct.

In the preparation of this paper and these tables, I have received much assistance and many valuable suggestions from Mr. W. J. Luther, Civil Engineer, a member of this Association; and I wish also to express my obligation to the members of this Association and others who have so kindly furnished the statistics of the works in their charge.

DISCUSSION.

Mr. WHITNEY. I thought I understood Mr. Coffin to estimate the consumption per capita for public uses at three gallons per day; did I understand him aright?

Mr. COFFIN. Yes; I thought that was a small estimate. Mr. Brackett's estimate, including fire consumption, was from four to five gallons. I based it on his estimate wholly.

Mr. WHITNEY. Judging it from one place with which I am somewhat acquainted, I should say it came nearer six than three. It seemed to me you were using a small figure.

Mr. COFFIN. I used that so as to be entirely on the conservative side. I think my figures show that water works systems in New England are not insolvent or in danger of insolvency, and I thought in making this estimate of the proper amount to be credited to the works for public uses, it would be better to be on the conservative side than to strain a point.

Mr. CRANDALL. I would like to ask Mr. Coffin if he found that it was usually the custom in replacing lines of pipe to charge it to expense or construction. I am frequently instructed to replace a lot of cement pipe with iron pipe and to charge it to current expense. I understood him to say the general custom was to do otherwise.

Mr. COFFIN. I did n't say exactly that. I could not say from the statistics I have received just what the general custom is. In some cases extensions are charged to maintenance, and in other cases they are charged to construction. There does not seem to be any rule or principle or any regular custom about it; some works do one way and some another.

Mr. CRANDALL. There are a great many works replacing cement pipes, and it would seem to be advisable to have some uniformity in the way of keeping the accounts.

Mr. COFFIN. I think in some cases renewals were reported as charged to the maintenance account. I think the tendency is to swell the maintenance account by construction rather than to swell the construction account by items which should be charged to maintenance. It seems to me that there should be some definite rule about it which should be followed. Of course, in any particular place they could pay for whatever construction they chose out of their current receipts, but as a matter of bookkeeping it should be definitely

stated, and there should be an agreement, and it should be understood what constituted maintenance and what construction. That was the point I was trying to make. It is very indefinite at present.

The PRESIDENT. Did you state that the average cost was eleven and one half cents per thousand gallons?

Mr. COFFIN. The average cost of water recorded at the pumps, based on the interest on the first cost of construction, one and one half per cent for depreciation, and the cost of running expenses was eleven and one half cents. The consumption of water is generally based on the amount of water the pumps record.

The PRESIDENT. The measurement of the pumps?

Mr. COFFIN. Yes; but in the ordinary running of the pumps there is a great deal more slip than there would be in running a pump on a test. In running a pump on a test, the length of a stroke is noted and everything of that kind; but in figuring for the amount of water consumed, the number of revolutions is taken into consideration and the length of stroke is not. It might be that there would be a loss of ten per cent between the amount figured from the displacement of the pumps and the actual amount of water passing through the pipes.

The PRESIDENT. You take into account the cost of distribution?

Mr. COFFIN. Yes, sir; everything up to the time of delivery to the consumer. The point I was making was that on Mr. Brackett's figures, backed up, of course, by the experience of most of us, no such amount as is registered at the pumps could be registered at consumers' meters. Mr. Brackett, if I am not mistaken, sets the figure in several places for the amount which can be registered at the meters at from fifty to sixty per cent of the amount of pumpage.

Mr. CRANDALL. I would like to ask Mr. Coffin if he has ascertained whether in these places where they speak about the small proportion of the pumped water being accounted for, they know how much water is used in watering-troughs and fountains, and for public purposes, or whether that is estimated. I have always thought that that was where the water went rather than through leaks in the mains.

Mr. COFFIN. What I said on that part of the subject was taken entirely from Mr. Brackett's paper. He made a very careful study, as I understand it, of the matter in the number of places, and endeavored to take into consideration everything that was going on, and in places where the water was metered to quite an extent; and there is no doubt he has given us the best thing we have of the kind.

I agree with Mr. Crandall that there is a great deal of water wasted at the drinking fountains and watering-troughs. I have seen cases, and have protested against it, where there was probably ten times as much water running in and out as there was any chance of using at all.

Mr. FULLER. I would say that at Wellesley, where all our services are metered, we find that the metered water amounts to about fifty per cent of what we estimate is pumped. I have no doubt myself that there is some leakage in the pipes, and I have been using my influence in endeavoring to have the system tested. I believe that there is more water running to waste through leaks in the pipes than we are aware of. I know at Arlington, after the high service was completed, we carefully tested the whole system, and we found some quite serious leaks which I don't think would have been discovered if we had n't made the test; and as the result of it the apparent consumption was a good deal reduced. I am inclined to think it would be a good plan if works were thoroughly tested every few years; and I believe if that were done a large amount of water would be saved.

The PRESIDENT. Have you in mind, Mr. Fuller, any method of making such a test as you suggest?

Mr. FULLER. The method we have adopted in several instances has been, first, to go over the system with a small testing pump, which, perhaps, would cost, fitted up, thirty dollars. That will give an idea of whether the pipes are tight or not. By shutting off the system into as small sections as possible, and attaching the pump to a hydrant, it can very soon be ascertained whether a section is tight or not, by the capacity of the small pump. If it is, that is all that needs to be done to that section. If it is apparently not tight it is necessary to use a steamer, or some large pump, that will throw more water; and by running that up to a certain speed, of course, if the pipes are reasonably tight, or the leakage is only small, the pressure will increase, and if there is any large leak or any crack in the pipe, the pressure will probably break the cracked pipe, and it will show on the surface. I think this is something which ought to be done to every new system, and I think it would be a benefit to old systems to test them in the same way.

The PRESIDENT. I remember Mr. Jones, who was for many years superintendent of the Eastern Division of the Boston supply, bring-

ing into the office one day a hub that had evidently been leaking for a great many years. The water had been escaping so long it had made a sand blast around it, and it had cut such a distance into the hub that it had weakened it so it finally gave way and there was a break. I do not see why it is not possible that this same sort of thing may be going on in a good many places we know nothing about.

Mr. CRANDALL. The President's anecdote reminds me of something which happened just before I came from Burlington. There was a cave-in on one of the streets, and on digging out I found half of a half-inch brass corporation cock in the hole in the iron where it had originally been placed, and the other half had entirely disappeared, evidently worn away by the action of the water and sand moved by the water. The galvanized iron pipe which led from this brass cock had also been worn off on one side and a hole made through it for a distance of several inches, — a piece cut right out, worn out smoothly.

In relation to the annual laying aside of a certain amount of money for a sinking fund to cover depreciation, I recently heard advanced by an eminent financier the theory that he was not afraid of any debt on which he was able to pay the interest, and considerable was said in favor of having no sinking fund for any public debt. I do not know whether or not that is to be the coming way of providing money for public uses, but it was a very eminent gentleman who was advocating that plan in connection with raising $100,000 for the city of Burlington.

Mr. COFFIN. Possibly a short description of the method I employed to discover leakage in the system I spoke of in my paper may be of interest, as the subject has come up, and as the matter is an important one. The town to which I refer has about one thousand inhabitants. It was brought to my attention that there was apparently a very large consumption, that the water in the standpipe went down about as fast in the night as it did in the daytime, and it was thought something must be wrong. I suggested that we have the cards of the telemeter at the standpipe and the pumping cards. I inspected those cards and I found that out of a total pumpage of about 300,000 gallons per day, there was a difference between the twelve hours from six A. M to six P. M. and the same time at night of about 35,000 gallons only; that is, there were only 35,000 gallons more used out of the standpipe in the twelve day hours than there were in the twelve night hours. This was in the fall, when there was

no great draught for hose purposes and no wasting to prevent freezing at night. That suggested to me a method of finding out what was consumption and what was leakage from the mains and from the services. I considered that under normal conditions seventy-five per cent of the consumption would be in the twelve day hours, and twenty-five per cent in the twelve night hours. If that was the case, then the difference between the normal consumption of the day and night would be fifty per cent. Now, if fifty per cent was that difference, which in that case was observed to be 35,000 gallons, then the total consumption was about 70,000 gallons. Using that as a basis, that there were 75,000 gallons consumed legitimately, that left 225,000 gallons as the leakage. Following this up, our method of locating the leaks in the different streets was to shut off a certain section or let it on, as the case might be — I won't go into the details of that — and watching the card at the standpipe. We shut it all off at first and found there was no leak in the standpipe, and then we let on a section, and one section after another, and figured the leak from the standpipe. The telemeter, of course, gave us the curve of the water going down in the standpipe. We made the test at night, so the pumping did not come in. And following out this method, which I think was approximately correct, we located leaks in several streets and different sections.

The PRESIDENT. Did you dig down in those places?

Mr. COFFIN. That has n't been done yet. It came on cold weather and we could n't do it then, but it will be done this summer. It is going to be quite an expensive job, for we were not able to locate the leaks exactly.

Mr. HATHAWAY. In making the test on a section of pipe, what arrangements were made in regard to house services? How could you control them so as to tell whether the water was going into them or leaking from the main? Was every house service shut off?

Mr. COFFIN. No, sir; there was none of them shut off. We did the testing between eleven o'clock at night and two o'clock in the morning, during which time, of course, the legitimate consumption would be very small, so if we found a large amount of water going into a short street, we would assume it was not due to consumption.

Mr. NOYES. I would like to ask Mr. Coffin if the 75,000 gallons were determined entirely as stated or whether the further testing of the standpipe indicated the same condition?

Mr. COFFIN. Yes, it indicated practically the same thing.

Mr. FULLER. I think it will be interesting to know if any members here are connected with works in which water actually pumped is checked in some way independent of the pump; that is, if there is anything used similar to a Venturi water meter? I have often thought that would be an excellent thing, for I have no doubt pumps give too high a record of pumpage, especially after they have been used some years.

The PRESIDENT. Can any gentlemen answer Mr. Fuller's question?

Mr. CRANDALL. We made a short experimental test in that direction in Burlington by checking the registration of our pump by the registration of our meter, a number of years ago. That was done for a definite purpose, when certain parties advocated changing the pumps, and others thought the pumps we had could be repaired, and they cut out a line from the pumps to the reservoir, and for some time checked the registration of the pump by the registration of the meter. The strokes of the meter registered a certain number of gallons and the pump record was compared to that. I do not remember now what the comparison showed.

Mr. COFFIN. I think there should be a great deal more attention paid on all water works to recording different items, especially of the consumption of water. I think I had returns from ten gravity systems and only two out of the ten returned the consumption of water. I believe every gravity system, and I advise it in my own practice, ought to have a meter of some kind or some form of weir measurement to measure the consumption of water. That is, of course, one of the first points an engineer has to meet, when he is called to investigate a gravity system of water works, and if he does n't know the consumption he does n't have any starting point for his figures. He can scarcely know what to do until he can get some determination of the amount of consumption. So I claim it is just as important a part of water works construction to have some form of measurement of the water, if there is no pump, as any other part, and as perfectly legitimate an item of expense.

The PRESIDENT. In my own experience I have come across some long mains that were perfectly tight. I tested a force main a mile long not a great while ago and found it tight. At the end of that main we had a weir and a large weir-box, and that gave the measure of leakage. But we all know that there are different ways of laying pipes. I have in mind another pipe a mile in length, laid under

inspection, too, which was so poor I never dared let the water on to it with any great velocity; but someone else did at one time, and then just what I had feared happened. On examining the joints we found that on the under side of the pipe they were not leaded in almost every place. I should like to have some gentleman here say a word on that subject. It seems to me it is an important one. There are a number of town supplies where the head is such that there is none to spare, and where it is a matter of great importance to keep every foot of it. And yet, where pipes are laid carelessly there is more or less leakage, which means loss of head at every point. I think this paper is an extremely useful one, for it brings up many just such matters.

Mr. McNALLY. I think Mr. Bates has been making some experiments lately which it will interest us to hear about.

Mr. BATES. I hardly know to what the gentleman refers. If it is to leakage, I am glad to be able to say I don't think we have any leaky pipes. There are some places in our town where more head is required, and the question which is now agitating us is whether to pump the water or to secure the extra head by constructing a storage basin higher up than where our basin now is. The problem has been referred to an eminent engineer, Mr. Allen, of Worcester, who is working it out, and perhaps I may be able to give you some information with regard to it later.

Mr. McNALLY. The point I had in mind was that, knowing Mr. Bates had put in a Venturi meter recently, he might have discovered something interesting from it.

The PRESIDENT. How large a meter did you put in?

Mr. BATES. A 16-inch Venturi.

The PRESIDENT. Did you place it near the pumps?

Mr. BATES. We have no pumps; it is a gravity system. I have n't as yet made a sufficient test to prove the tightness of the pipes, but that can be done later on. I have tried the meter in this way: I shut off a part of the system and connected with the upper section of our town, and there was a registration of 13,000 gallons in twelve hours of water supplied to about one thousand people, which was a very low registration. The test was made under very favorable circumstances however, being on a very wet Sunday when there was no sprinkling and nothing to raise the consumption. This was in a farming district. The small amount per capita showed there could not be much leakage on that line.

The PRESIDENT. Wherever I have seen cast-iron pipes open in the street, and I have seen a great many of them, I have always taken pains to look at the joints, and it is surprising how many of them I have found leaking. Often a joint which is apparently perfectly tight will be seen upon a close examination to show a slight leak.

Mr. BATES. I would like to ask if it is customary among water superintendents to have all main pipes tested before covering?

Mr. FULLER. I don't think they can be on new works very well.

The PRESIDENT. I never saw it done myself.

Mr. COFFIN. On new works it cannot be done usually, but it seems to me very desirable. It certainly would show up any small joint leaks. A small leak can go on for a long time unnoticed at the surface, and even large leaks where there are culverts or sewers to carry the water away. I have seen a case where the water from a large leak flowed underground to a culvert 1,000 feet away, and it would not have been noticed except we knew there was a leak and hunted it up. It might, perhaps, in dry weather, but there was at the time nothing to call attention to any special flow of the stream.

CORRESPONDENCE.

Mr. HAZEN. The paper presented is extremely interesting as showing some of the principles which should be taken into account in calculating the cost of delivering water to consumers. While no direct statements upon that point are made, it is implied that the charges to consumers should be only sufficient to meet the actual cost of supplying water after the city has paid, from funds raised by direct taxation, for the value of fire protection. This theory of fixing the rates is extremely common in America and has much to commend it, but I think it will perhaps be worth our while to remember that there are other theories which might be, and often are, taken into account in establishing water rates.

As Mr. Coffin states, "There is no service (unless it be the postal service) in which people receive so much that contributes to the necessities, the convenience, and the luxury of living from the same expenditure, as they do from a well built, well managed system of public Water Works." The price of a commodity is ordinarily limited by two facts: it will not be supplied for less than its cost to the one delivering it, nor can it be sold for more than its value to the purchaser. These two limits may be, and often are, far apart, and

the difference between them, representing profit, is usually divided between the two parties in proportions varying widely with the conditions of business. No one will question that the value of pure water to consumers is ordinarily much greater than its cost to the city, and in the case of private water companies it is regarded as proper and just to charge a price somewhat above the cost of production as a product on the business. When the matter is taken in hand by the city, this profit is often abolished, or rather given to the consumers, on the theory that it is for the best interests of the citizens, to supply water at the lowest possible figure, that is at cost, but we must not forget that a natural, ordinary price, as measured by general conditions of private business, is somewhat higher than this.

It is the latest American fashion, following long established European precedent, for cities to receive compensation for franchises which they grant to private companies. In case of many of the newer contracts made in this country with street car lines, electric light companies, etc., the companies, in addition to their taxes, are required to pay large sums of money into the city treasuries, and these funds are used to help pay the general expenses of the city government. It would be eminently proper for the city to require a water company to make such payments and to use the money for general expenses. Why is it not equally proper and desirable for the city to charge such reasonable price for the water as will turn a substantial profit into the city treasury, to be used for current expenses? Any system of taxation is more or less unequal, and it is perhaps an open question whether revenue raised in this way will not be as fairly distributed among those who ought to contribute to the support of the government, as from any other source; and so long as only a reasonable price for water is charged, which is far below the value of water to the consumers, it is not apparent that injustice is done to any one.

Further, there are many expenses indirectly connected with the supply of water which have to be borne by the city and which, if they are not met from the sale of water, have to be paid for out of the general tax levy. No sooner has a town introduced a system of water supply than there is a demand for sewers involving a heavy expense to the town, directly due to the introduction of the water. Sometime after sewers are constructed the sewage can be allowed to flow into the nearest stream without further expense, but oftentimes the sewage has to be carefully collected, pumped and purified,

or at least clarified, before it can be discharged, and the expense thus incurred not only follows directly the introduction of the water, but is measurably proportional to the amount of water used; and for every gallon of water used or wasted, the city has to pay twice; once for its collection and distribution as water and once for its collection and disposal as sewage.

It has seemed to many of those in charge of European municipal affairs that it was eminently proper to charge a price for water which, in addition to the whole cost of supplying the same, would pay a portion or all of the cost of disposing of it as sewage, and I question if we cannot, with advantage, adopt this idea under American conditions. It is certainly desirable to have as low rates as possible, but I believe, in the long run, the best interests of American cities will be served by securing thoroughly adequate and pure supplies, and by charging rates high enough to pay all the costs connected therewith, either directly or indirectly, and I see no valid reason why, in a country where indirect taxation by tariffs, internal revenue, etc., is as popular as it is in this country, cities should not derive in addition, a moderate profit from the business which they undertake and to which they lend their credit, turning the same into the general funds available for paying expenses, and thereby lowering the tax rate.

Mr. COFFIN. It is certainly desirable to examine the subject of the basis of water rates from various standpoints. I do not believe, however, that the principle suggested by Mr. Hazen is a correct one for a basis of rates, or that the theory of charging for water more than its cost, is a proper one when such service is undertaken by the municipality.

In governments that are run for the benefit of the rulers it is consistent to require compensation for franchises of monopolies of public service. Under a democratic form of government when such service is intrusted to private companies it may be the best way in which the public can be compensated for the excess of profit derived from a monopoly.

Public service when undertaken by the people themselves through their municipal government is a form of co-operation, and the service should be performed at cost to those served. There is no good reason for making a profit on one form of service in order that other forms may be done for less than cost.

All forms of service, such as roads, bridges, schools, etc., the

money for which is raised by a general tax levy, are done at cost. It almost seems absurd to speak of profit in connection with them.

The water service differs from these only in the method of collecting a portion of the cost; a part of it (approximately that part due to fire protection) is usually raised by taxation, while the cost of the domestic and manufacturing service is met by rates that are based in some manner upon the quantity used.

The introduction or the maintenance of an adequate supply of pure water should not be discouraged by burdening it with the necessity of producing a profit, whereby the cost of other forms of service, no more necessary or beneficial, may be lessened.

The value of the service to the individual should not enter into the question of price. The value of water may be infinitely great if there is but one source from which to obtain it. Nor can the cost to the individual of obtaining an individual supply be a measure of the price, or form an argument for profits. As well say that because the cost to each man of a private road to market, etc., would be great, that a profit should be made upon road service and used to reduce water rates. In fact, there seems to be no more reason for making a profit on water than on other forms of public service.

The soundness of the argument for basing water rates upon cost is tacitly admitted by Mr. Hazen, for he favors higher rates in order to meet expenses indirectly caused by the supply of water. A sewerage system is cited as an example of such indirect expense. It is certainly true that all expense really caused by a water supply, whether directly or indirectly, should be figured as a part of its cost. The necessity for sewerage, however, cannot be attributed to the introduction of a water supply. Instead of this, such introduction usually renders the need of sewerage less imperative. While a town is supplied with water from wells, sunk in the populated territory, the danger from sewage pollution is great if the influence of drinking water upon disease is as great as it is now supposed to be. As soon, however, as a supply is taken from a pure source outside of the populated district, the danger is greatly lessened, and in many cases properly managed cesspools can safely care for the sewage for some time.

While the introduction of a water supply does not necessitate sewerage, a modern sewerage system does require a water supply, and for this reason the construction of sewers often follows the introduction of water. This fact may give rise to the belief, more or less general, that the need of sewers is caused by water works.

Instead of the cost of sewerage being a legitimate charge upon water works, the sewers are indebted to the latter for a vehicle by which to transport the wastes that really demand the sewerage system, and in strict justice should not only pay for water for flushing purposes, but a portion of the expense of the water supply.

It is certainly desirable that the revenue from water rates should be large enough to bring the water service to the highest degree of purity and efficiency, but I believe it is in every way undesirable to attempt to secure a profit from the service or charge it with any expenses not legitimately its own.

PROCEEDINGS OF THE FIFTEENTH ANNUAL CONVENTION.

LYNN, MASS., JUNE 10, 11, AND 12, 1896.

The fifteenth annual convention was held at Lynn, Mass., June 10, 11, and 12. The headquarters of the Association was at the Hotel Seymour, and the sessions of the Convention were at the hall of the Oxford Club. Meetings were held on the afternoon and evening of June 10, and on the morning and evening of June 11, for the reading and discussion of papers, and the business meeting on the mornings of June 10 and 12.

WEDNESDAY, June 10, 1896.

The Convention was called to order by President FitzGerald, who said :—

"I have to welcome you, ladies and gentlemen, to the fifteenth annual convention of the Association. We have n't Lake Champlain before us, but we have something which perhaps equals it, the beautiful shores of Nahant and the invigorating sea breezes from the ocean. I have now the pleasure of presenting to you His Honor Mayor Bessom of Lynn, who will say a few words to you in the way of welcome."

ADDRESS OF WELCOME BY MAYOR BESSOM.

Mr. President and members of the New England Water Works Association and guests: It gives me great pleasure in behalf of our municipality to welcome you here to-day. I think Lynn ought to feel honored that you have chosen this place for holding your convention. My pleasure at meeting you here is two-fold. I think it may be of some advantage to the members of this Association to know something about Lynn, but I think it will be of greater advantage to the people of our city to become acquainted with the methods of work and the reason for the organization of the New England Water Works Association; and I have no doubt they will derive that infor-

mation through the medium of the press in the full reports of the doings of your Association while you are in this city.

In regard to our city, of course you know it is one of the oldest of the New England communities, having been settled in 1629; and it is to-day one of the objects of the pride of our Commonwealth, and one of the great hives of industry with which not only Massachusetts but the whole of New England is dotted. And we feel particularly proud of our success because it has not been due, perhaps, to natural advantages, but to the industry and the perseverance and the integrity of the people who make up our community. And that perhaps is not something peculiar to Lynn, but it may be said to be characteristic of all of our New England communities, and certainly not less so of Lynn than of any other city.

Lynn, as I have said, was settled in 1629 by people who came here from Salem, which was the first point of permanent settlement in Essex County. I suppose they felt they were a little crowded in Salem, although we might not think so to-day, and so a few of the Salem settlers came over to Lynn and set up a separate community which was known at that time as the Third Plantation. The first line of demarcation between the townships in Essex County was a line from some rock upon the seacoast up through one of the little islands in one of our beautiful lakes, separating at that time the town of Salem from the town of Lynn.

Lynn has gone on from that small beginning, until to-day we claim that we are the largest manufacturing centre of the world. We have here also, at West Lynn, the large electric works, and we have a large number of other interests, so many that one does not realize the number until he looks through the directory. We have a population of sixty-two thousand people, and we think this is a prosperous community and a good one in which to live.

We have also many natural advantages in the way of beautiful scenery, some of which I trust you will be able to see, and I hope when you return to your homes you may carry with you many very pleasant memories of your visit here.

Now, in regard to the Association. The people of the country, and of course that includes the people of Lynn, probably know but very little about the New England Water Works Association, and yet it is one of the most important organizations, I think, that has been formed in recent years. If you did not meet together and have

the opportunity thus afforded for the interchange of your observations and information deduced from your practical experiences, each man would be left to go along in his own way, and to solve by his own experiments his own difficulties in a way he would think best for himself. But by coming together and listening to the papers which are read, you gain the knowledge and experience of all, and each is made the richer; and by each one being made so much the better informed, the better can he serve the community in which he lives and labors, and thereby the communities receive the benefit of your meetings. And therefore I say that I am glad that you are here in Lynn, that our people may become acquainted with you, and that they may know that this matter of providing suitable water for our domestic uses is being kept abreast of every other subject of municipal interest in this latter part of the nineteenth century.

Now, gentlemen, I do not care to detain you, because I know you have your business to transact, and therefore I will close by welcoming you most heartily to the hospitality of our city. I thank you, Mr. Chairman and gentlemen, for your attention. [*Applause.*]

RESPONSE BY PRESIDENT FITZGERALD.

Mr. Mayor: In behalf of the New England Water Works Association, I desire to thank you for your cordial reception, and to assure you that we believe we shall carry away from your beautiful city far more than we bring to it. As you have said, I hope it will be for our mutual benefit; but I think it will be more for our benefit than for yours. The enterprise and the energy of your people have been well-known to us for many years. Ever since that little manufactory was established on the banks of the Saugus River in 1642, and which I suddenly came upon the other day in a trip I was making through your city, the energy and enterprise of your citizens have been well-known to the whole world. Boston may be the hub of the universe, but this is where we look for the centre of our understandings. [*Laughter.*] But if I were to take one to Lynn to show him what seems to me to be the most attractive side of Lynn, I shall not show him her business enterprises nor the evidences of the public spirit of her inhabitants, but I shall call his attention to the wonderful topography of your city, the beautiful outline of the shore, stretching away to Nahant, that beautiful beach, and I shall take him to High Rock,

one hundred and fifty feet above tide, from which such a magnificent view of forest and of sea can be enjoyed. Then I would take him further inland into that beautiful park which with so much enterprise you have recently given to the public. That seems to me to be a particular jewel of which you may well be proud. And I must confess, that when I first made a trip through the Lynn Woods, as they are called, I was amazed. It does not seem possible that so near to Boston there can be such a stretch of beautiful natural woods, with such a variety of outline, such beautiful valleys, and such high hills commanding such magnificent outlooks. Your city certainly owes an eternal debt of gratitude to Mr. Philip Chase for the energy, the courage and the skill with which he got together those pieces of ground forming the Lynn Woods and, with the assistance of other of your noble citizens, secured them forever to the use of your people. I trust, Mr. Mayor, you may be able to attend our meetings and that you will enjoy our papers. Thanking you again, sir, I will ask the Convention to proceed with the regular order of business. [*Applause.*]

ELECTION OF NEW MEMBERS.

The Secretary presented the following list of applicants for membership, with the approval and recommendation of the Executive Committee: —

RESIDENT ACTIVE.

John E. Smith, Superintendent, Andover, Mass.
Emory A. Elsworth, Civil Engineer, Holyoke, Mass.
Frank S. Badger, Assistant Engineer Locks & Canals Co., Lowell, Mass.
D. W. Tenney, Water Commissioner, Methuen, Mass.

NON-RESIDENT ACTIVE.

C. B. Bryant, City Engineer, Martinsville, Va.
John F. Miller, Secretary and Superintendent, East Pittsburg, Pa.
Henry Metcalfe, Water Commissioner, Cold Spring, N. Y.
H. D. C. Richards, Manager Water Works, Conneaut, Ohio.

On motion of Mr. Fuller, the Convention instructed the Secretary to cast one ballot in favor of the candidates, which he did, and they were declared elected members.

On motion of Mr. Crandall the reading of the records of the last meeting was dispensed with.

ADDRESS OF PRESIDENT FITZGERALD.

LYNN, June 10, 1896.

Gentlemen of the New England Water Works Association:

The Fifteenth Annual Convention marks another year in the history of this Association. It is a fitting time to review briefly the perspective of the past, to glance at our present position, and to turn our faces to the future so fast approaching us. To moralize is almost always wearisome, and from this your retiring President will endeavor to refrain; but one can hardly turn the pages of our record backwards without being struck at the steady, persistent progress of the New England Water Works Association. Here is a concise table of membership from the foundation to the present time.

YEARS.	Active Members.	Associate Members.	Honorary Members.	Total Membership.
June 21, 1882 . . .	27	—	—	27
" 1, 1883 . . .	37	6	—	43
" 19, 1884 . . .	48	Fine 9	—	57
1885 . . .	83	44	—	127
1886 . . .	106	47	—	153
1887 . . .	142	51	1	194
June 13, 1888 . . .	181	54	3	238
" 1, 1889 . . .	209	64	4	277
" 3, 1890 . . .	257	73	5	335
" 1, 1891 . . .	281	74	5	360
" 1, 1892 . . .	290	70	5	365
" 1, 1893 . . .	338	69	5	412
" 11, 1894 . . .	365	73	5	443
" 1, 1895 . . .	401	81	5	487
" 1, 1896 . . .	442	82	5	529

From this table it appears that all the classes of membership are growing; none more persistently than the active member. We must not forget that one of the best foundation stones in our edifice is the Associate member. It is to his skill and enterprise that many of the best advances in water works are due. Without the emulation which springs from competition in the useful arts many of the undertakings which are now so easy of accomplishment would fall to the ground. It is to the workshop and the foundry that we turn for the means of accomplishing some of our best inspirations.

As far as numbers are concerned, we may congratulate ourselves upon the upward rise of the membership curve, but it must be borne in mind that it is not from mere increase of membership alone that a society derives its real strength. It is rather in the ever growing number of those who take an active interest in the welfare of the Association, who attend the meetings, who take part in the literary exercises and discussions, and who give freely from their store of knowledge and experience, that the real vital power of an association is felt and its influence established. It is from this standpoint that our work in the past seems to offer the highest encouragement. The meetings have been growing steadily in interest and activity, and while pervaded with the best spirit of goodfellowship there is always visible a strong undercurrent of earnest desire to learn something to keep fully abreast with the progress of the times and to advance the general cause in which we are embarked.

Let us examine for a moment the work which the Association has been engaged upon during the year just closing, for it is from this kind of a survey that we arrive at the clearest idea of our present position.

During the past year papers on the following subjects have been submitted: Electrolysis; Caloric determination of the value of fuel; Water supplies of Lynn, Burlington, Manchester, St. Louis, Waterbury, and Milford. Uniformity of methods in testing water meters; Tests of articles of commerce to be conducted by the Association; The Metropolitan Water Supply of Massachusetts; The sanitary condition of the water supply of Burlington; An electrical pumping plant; Water borne diseases; Description of second-tube well plant at Lowell; Handling fires while changing distribution mains; The friction in several pumping mains; Some notes on the formation of tubercles in iron and steel penstocks; The appearance of Chara Fragilis in the reservoir of a public water supply; Recording pressure gauges; Water filter at the Milford water works, and Anchor ice.

This list of subjects shows the wide range of topics covered by the papers delivered before this Association. It goes without saying, that both the papers and the discussions ensuing have proved valuable contributions to water supply literature.

Our convention at Burlington in September last will not soon be forgotten. It was a particularly enjoyable occasion. The beautiful

sails on Lake Champlain, the picturesque trip through the Ausable Chasm, and the cordial hospitality so freely bestowed cannot soon fade from the memory.

In one of the advancing steps which this Association has quite recently taken, it seems to me we may feel especial pride. On May 20 we met with our sister society, the Boston Society of Civil Engineers, in the Tremont Temple, and after a most enjoyable banquet opened our permanent headquarters in that new building which has just been erected in the very heart of the city. Here we have a large room comfortably furnished and provided with current magazines, tables at which we may read and study, and desks at which we may write; and here we have started a library in which we trust all members will take an interest and will feel it a matter of honor to foster. With the consent of the Executive Committee, a circular has recently been prepared, and it will soon be sent out all over the country asking for contributions of books and pamphlets for our shelves. The library will be devoted to the subject of Water Works in all its various branches, and perhaps before many years the Association may find itself in possession of a valuable collection of water works books. I trust that the new headquarters will prove a convenience to non-resident members as well as to those who live in the city, for here certainly they will find a quiet place in the busy part of the Hub where they can retire for conference or for study.

If we, as an Association, feel a certain satisfaction in reviewing the past and the present, what should be our thoughts as we turn to the future? One of the surest ways of judging the future is by the past, and by this standard it seems to me that the outlook is a cheerful one. It is an almost every-day expression that we hear about us, "The water works question is getting to be an important one," and nothing can be truer. As we look around we find that almost all the large cities in the country are laboring with the gigantic problems connected with the growth of their water works systems, while the smaller cities and towns are either extending their works or combining for mutual benefit, and even the villages are beginning to waken to the advantages of public supplies.

With all this restless activity in our common interest, it does not seem possible that the future has not some marvellous surprises for us, even when our imaginations are stimulated to the utmost.

One of the most important problems that confront the water works

official, is the question of the reckless use or abuse of water. While many excellent papers have been written on the subject of waste, and none abler than those found in our own transactions, much work still remains to be done in this direction. Enormous sums of money are lavished in the extension of supply systems, but in the majority of cases without succeeding in the effort to get ahead of the consumption. Here is indeed a wide field for patient investigation, and particularly for the display of courage, for it is not always a popular task to limit the use of water to legitimate purposes. A great educational work remains to be undertaken, but the reward is surely ready for those who have the talent and energy to bring about reform.

I have already alluded to the activity going on about us in every direction, connected with water supplies. In every development of this kind New England stands well to the front. It is unnecessary for me to allude to many of the grand enterprises now under way under the direction of members of this Association. You are all familiar with the unique system, already under construction, known as the Metropolitan Water Works of Massachusetts. A system which looks far into the future and which unites in one great chain, stretching westward from Boston, Cochituate Lake, and the Sudbury, Assabet, Nashua, Ware, and Swift rivers. Never before was such a far-reaching scheme started with so little opposition and under such harmonious auspices.

On the borders of New England we find that great metropolitan centre, New York, also engaged in works of grand proportions, unequalled, so far, in the history of the world, and these works are largely under the care of members of this Association. Some of the New York work may not be entirely familiar to the present audience, and at the risk of wearying you I will give a brief résumé of the leading features.

The city of New York is fortunate in having such an excellent source of supply as the Croton River. Almost its only drawback is the fact that even when the present works for its full development are completed, the city in a very few years will be obliged to seek an additional source. The watershed is an excellent one, comparatively free from swamps, and containing a very small population. Its area is three hundred and sixty square miles. A dozen years ago, and after the old Croton aqueduct had supplied New York for

nearly half a century, its capacity was overtaxed and it was found almost impossible to meet the daily consumption, which was then about 110,000,000 gallons. The only way in which the city could be saved from an absolute water famine was by throttling the gates at Central Park reservoir and reducing the pressure in the mains.

An extensive scheme of works was at once planned and carried out, and it certainly constitutes the most stupendous system in the nature of water supply that the world has ever seen. A princely sum was at once put at the disposal of the Commission, $50,000,000. Almost the whole of the additions have either been completed or are in process of execution, and we are in a position to judge of their extent and quality.

The chief peculiarity of the new Croton aqueduct, already completed, lies in the fact that it is almost entirely in tunnel. It is practically thirty-three miles long and has cost $20,000,000, or from $90 to $123 per linear foot. It is of horse-shoe section and equivalent to a 14-ft. circle, and has a capacity of 302,467,000 gallons daily. Seven miles are under pressure, a bold innovation, but which has proved successful. The total leakage outwards in this seven miles is about 228,500 gallons daily, although the maximum pressure is 100 feet head of water. The masonry part of the structure terminates at 135th Street, and from this point eight lines of 48-in. pipe, laid side by side, extend to different points of the distribution system.

While the new Croton aqueduct was building, several very large storage basins were constructed upon the watershed, involving many interesting features. The largest one of all, formed by the Cornell dam, was begun about two years ago. It was estimated that by providing 55,000,000,000 gallons storage, the Croton might be developed to the extent of providing 250,000,000 gallons daily. When the new aqueduct was completed in 1891, the consumption of water in New York rose to 165,000,000 gallons daily, and it is now about 200,000,000 daily, so rapidly is the capacity of new works taxed, if wise restrictions are not placed upon the consumers' end of a system. The available amount of water stored, when all the basins are built, is about 75,000,000,000 gallons.

It was stated that $20,000,000 had been expended on the aqueduct; $10,000,000 more have been expended on the watershed. The new Croton dam will cost $5,000,000; the Jerome Park reservoir $5,000,000 more; making $40,000,000, out of the total $50,000,000

appropriated. The new Croton dam at Cornell's is such a magnificent undertaking that it deserves something more than a passing notice. Statistics, however, are wearisome. It may suffice to state that the dam will be the largest ever constructed by the hand of man. It will be 260 feet high and 190 feet thick at the base which is to repose on the rock more than 100 feet below the river. The water at the dam will be 140 feet deep, but the dam has to be built to withstand a head of over 250 feet. Although the dam was begun more than two years ago, yet the foundations are not even laid. The spill-way which is partly cut out of the side hill, and extends up stream at right angles with the face of the dam, is to be 1,000 feet long, or about the same length as the dam itself.

The Jerome Park reservoir, now begun, will undoubtedly be the finest, most elaborate, and most expensive distributing reservoir in the world. It will hold 7½ days' supply. The Central Park reservoir holds 5 days' supply,— making a total of 12½ days' storage inside of the city. I have gone into the description of the New York works at some length, because they form a type on so large a scale of our American practice.

If we look across the water, however, we find that the same activity, in the direction of extension of water supplies, exists there as in our own land. London is now considering several plans which almost excel any on this side of the Atlantic; Liverpool has built the Vyrnwy dam. Hamburg has just completed its magnificent system of filtration; Paris is reaching out for more comprehensive plans, and the same is true of all the other centres of population in the Old World.

Would it not be a fine scheme if we could have, at some future day, a grand review or Congress of Water Works officials, from all over the world? And what more appropriate place for a meeting could be selected than Boston? The inauguration of the Metropolitan system would afford the excuse, and the execution of the plan would be an honor to this Association and a benefit to all mankind.

In conclusion, permit me to thank you for the kind consideration shown me during the past year. Owing to the nature of my engagements, it has not been possible for me to take as active a part in the labors of the Association as I should like to have done, but with the able supervision of the Executive Committee, the Secretary, Treasurer, and Editors, your business has been faithfully administered. To these officers I desire to extend my hearty thanks.

Since the last annual meeting we have lost by death six of our members: John L. Harrington, M. M. Tidd, C. F. Doherty, Horace L. Eaton, Fred I. Chaffee, and James H. Stanwood. Their last earthly work is accomplished, but their example remains as an inspiration and incentive for our own efforts.

REPORT OF THE SECRETARY.

SUMMARY OF STATISTICS RELATIVE TO MEMBERSHIP FOR THE YEAR ENDING JUNE 1, 1896.

Active Members.

June 1, 1895. Total active membership			401	
Withdrawals during the year			10	
			391	
Initiations:				
June, 1895	7			
September, 1895	26			
December, 1895	5			
January, 1896	2			
February, 1896	5			
March, 1896	6			
		51		
June 1, 1896. Total active membership				442

Honorary Members.

June 1, 1895. Total honorary membership		5	
" 1, 1896. " " "			5

Associate Members.

June 1, 1895. Total associate membership		81	
Withdrawals during the year		4	
		77	
Initiations:			
September, 1895	3		
December, 1895	2		
		5	
June 1, 1896. Total associate membership			82
June 1, 1896. Total membership			529

A gain for the year of 42.

SUMMARY OF RECEIPTS FOR THE YEAR ENDING JUNE 1, 1896.

Dr.

Received for advertisements	$1,340 00
" initiation	242 00
" annual dues	1,317 00
" Journals	168 00
" electrotypes	33 00
" badges	10 00
	$3,110 00

1895.		*Cr.*	
July 13.	Paid Geo. E. Batchelder, Treasurer		$700 00
Dec. 2.	" "		1,000 00
Dec. 31.	" "		500 00
1896.			
March 24.	Paid Geo. E. Batchelder, Treasurer . . .		300 00
June 1.	" " . . .		550 00
June 4.	" " . . .		60 00
			$3,110 00

On motion of Mr. Rogers, it was voted that the report be received and placed on file.

ANNUAL REPORT OF THE TREASURER.

GEORGE E. BATCHELDER, *in Account with the* NEW ENGLAND WATER WORKS ASSOCIATION.

1895.		*Receipts.*	
	Balance on hand as per last report		$2,673 03
July 15.	Received from J. C. Whitney, Secretary . . .		$700 00
Dec. 2.	" " " " " . . .		1,000 00
1896.			
Jan. 1.	" " " " " . . .		500 00
March 21.	" " " " " . . .		300 00
June 1.	" " " " " . . .		550 00
" 5.	" " " " " . . .		60 00
	Total amount received from J. C. Whitney . .		$3,110 00
Feb. 1.	People's Savings Bank interest		20 48
June 1.	Worcester Safe Deposit and Trust Company interest,		35 07
" 8.	City National Bank interest		14 36
	Total amount received from Secretary and interest,		$3,179 91
	Grand Total		$5,852 94

1895.		*Expenditures.*	
Aug. 22.	P. O'Brien & Son, basket of flowers		$10 00
" 24.	Byron I. Cook, expenses attending meetings of Committee		4 50
" 31.	Rockwell & Churchill, programme and circulars for convention		33 25
Sept. 4.	Geo. E. Batchelder, expenses to Springfield . .		2 24
Amount carried forward			$49 99

		Amount brought forward	849 99
Sept.	13.	J. C. Whitney, cash expended on account of Association	92 95
"	13.	J. C. Whitney, salary as Secretary to Sept. 1, 1895 :	125 00
"	21.	Bacon & Burpee, report of proceedings of convention at Burlington	116 60
"	25.	F. H. Crandall, cash on account of meeting at Burlington	35 00
"	25.	F. H. Crandall, cash on account of meeting at Burlington	54 96
"	25.	Electro-Light Engraving Company, one engraving diagram	1 14
Oct.	5.	Mercury Publishing Company, printing . . .	8 50
"	5.	Mercury Publishing Company, holding type four months	4 00
"	22.	J. C. Whitney, stamped envelopes for association .	116 70
"	28.	W. H. Richards, salary, travelling expenses, and typewriting	105 47
"		Rockwell & Churchill, printing	53 75
Nov.		The Day Publishing Company, printing September Journal	191 35
"	16.	Electro-Light Engraving Company, printing . .	13 76
Dec.	5.	" " " " " . .	11 63
"	12.	" " " " " . .	2 80
"	24.	Newton *Journal*, printing	13 75
1896.			
Jan.	1.	The Day Publishing Company, printing December Journal	214 12
"	1.	J. C. Whitney, cash paid out and salary to Dec. 1, 1895	153 13
"	4.	W. H. Richards, postage, expenses, and salary to Dec. 1, 1895	88 74
Feb.	26.	Newton *Journal*, printing	5 25
"	28.	F. H. Crandall, cash paid Burlington Photographing and Engraving Company	16 00
March	16.	Bacon & Burpee, reports of winter meeting . .	73 75
"	20.	W. H. Richards, cash paid out and salary to March 1, 1896	98 61
"	20.	J. C. Whitney, cash paid out and salary to March 1, 1896	167 78
April		Newton *Journal*, printing	63 80
March	21.	The Day Publishing Company, publishing March Journal	192 50
May	9.	Noyes & Hazen, office expenses of senior editor, postage, express, etc.	24 00
		Amount carried forward	$2,095 03

		Amount brought forward	$2,095 03
May	13.	W. M. Belcher & Co., one desk and chair . .	38 50
"	19.	David P. Page, bookcase for Association rooms .	65 00
"	21.	W. E. Parker, rent of chairs, etc., for rooms . .	7 53
June	5.	Electro-Light Engraving Company, engraving diagrams, etc.	15 08
"	5.	J. C. Whitney, cash paid out and salary to June 1, 1896	192 10
"	5.	W. H. Richards, cash paid out and salary to June 1, 1896	97 78
"	6.	Tremont Temple Building, chairs and services for dedication	14 00
"	6.	Cobb & Devlin, 6 oak arm chairs	15 68
"	6.	Fanning Printing Company, printing	3 00
"	8.	The Day Publishing Company, printing June Journal	492 04
"	8.	Boston Society of Engineers, rent to May 31, 1896 .	50 00
"	8.	Newton *Journal*, printing	27 75
"	8.	W. B. Badger & Co., one eight-foot table for rooms,	35 00
			$3,148 49

Balance on Hand.

People's Savings Bank	$1,052 64
City National Bank.	416 74
Safe Deposit and Trust Company	1,235 07
	$2,704 45

During the year, quarters for the Association have been rented in the Tremont Temple Building and furnished at an expense of $175.71, and rent paid to June, 1896, $50, making a total of $225.71 paid outside the ordinary running expenses.

Respectfully submitted,

GEORGE E. BATCHELDER,
Treasurer.

Approved by Finance Committee, { W. McNALLY. A. W. F. BROWN.

On motion of Mr. Chase it was voted to receive the report and place it on file.

At the afternoon session John C. Haskell, Superintendent, Lynn, Mass., read a paper entitled, "How to Secure Pure Water from a Surface Water Supply." The paper was discussed by Messrs. Cleaves, Noyes, Holden, Goodnough, Fuller, Hawes, and President FitzGerald.

Freeman C. Coffin, Civil Engineer, Boston, followed with a paper entitled, "The Financial Management of Water Works." This paper also led to considerable discussion which was participated in by Messrs. Whitney, Crandall, Fuller, Hathaway, Bates, and President FitzGerald.

The entire evening session was occupied by Mr. Jesse Garrett of Philadelphia, assisted by Mr. Prince. Mr. Garrett's subject was "The Making of Cast Iron Pipe," and his paper was illustrated by the stereopticon.

THURSDAY, June 11.

The morning session was called to order promptly at 10 A. M., and certain phases of the subject presented by Mr. Garrett on Wednesday evening were discussed and more fully presented by Mr. Noyes, Mr. Prince, Mr. Garrett, and the President.

The first paper of the morning was read by Lewis E. Hawes, his subject being "Utilizing a Spring as a Source of Water Supply for a Town."

Mr. F. F. Forbes, of Brookline, followed with a short paper on the "Method of Connecting Driven Wells to Suction Main and Manner of Laying Mains and Connecting with Pump." Messrs. Hawes, Whitney, Smith, Hyde, and the President participated in the discussion that followed the reading of the paper, or asked questions of the writer.

At the evening session Mr. George C. Whipple, Biologist of the Boston Water Works, read a paper entitled, "Some Observations on the Relation of Light to the Growth of Diatoms." Mr. Forbes supplemented the paper by a brief discussion.

F. W. Dean discussed the recent specifications for pumping engines for the water works of the city of St. Louis, Mo.

L. M. Hastings, City Engineer, Cambridge, Mass., gave an account of the extension of the Cambridge Water Works, illustrating his description by a series of stereopticon views, and subsequently he answered numerous questions put by Mr. Stearns, Mr. Fuller, Mr. Smith, and the President.

FRIDAY, June 12.

Vice-President Walker occupied the chair.

The Secretary presented the names of the following applicants for membership, duly approved by the Executive Committee: —

RESIDENT ACTIVE.

John N. Jordan, Superintendent, Malden, Mass.
John W. Crawford, Clerk, Water Board, Lowell, Mass.
Stephen S. Hatch, Water Commissioner, So. Norwalk, Conn.
Walter S. Brown, Registrar, Bangor, Me.
Thomas Roden, Superintendent, Arlington, Mass.

NON-RESIDENT ACTIVE.

Francis H. Luce, Superintendent, Woods Haven, N. Y.
A. Robinson, Superintendent, Benicia, California.

ASSOCIATE.

Garlock Packing Co. (Packing), No. 12 Pearl St., Boston, Mass.

On motion of Mr. Chase the Secretary cast the ballot of the Association for the above named candidates for membership, and they were declared elected.

Mr. Coggeshall moved, "That the thanks of the Association be extended to the Lynn Water Board, to the citizens of Lynn, and to all our Lynn friends who, by their various acts, have done so much to make our Fifteenth Annual Convention a success." Adopted.

On motion of Mr. Coggeshall it was also voted, "That the thanks of the Association be extended to the Salem Water Board and the citizens and ladies of Salem for their generous and cordial contribution to our entertainment."

ELECTION OF OFFICERS.

Mr. Stacey, for the committee appointed to nominate officers for the ensuing year, submitted the following report of nominations which was read by the Secretary: —

President. — JOHN C. HASKELL, Superintendent, Lynn, Mass.

Vice-Presidents. — H. T. SPARKS, Superintendent, Bangor, Me.; C. K. WALKER, Superintendent, Manchester, N. H.; F. H. CRANDALL, Superintendent, Burlington, Vt.; HENRY A. COOK, Superintendent, Salem, Mass.; WILLARD KENT, Manager, Narragansett Pier, R. I.; THEODORE H. MCKENZIE, Manager, Southington, Conn.

Secretary. — J. C. WHITNEY, Water Registrar, Newton, Mass.
Treasurer. — G. E. BATCHELDER, Water Registrar, Worcester, Mass.
Senior Editor. — ALLEN HAZEN, Civil Engineer, Boston, Mass.
Junior Editor. — W. H. RICHARDS, Engineer and Superintendent, New London, Conn.
Executive Committee. — H. G. HOLDEN, Superintendent, Nashua, N. H.; R. C. P. COGGESHALL, Superintendent, New Bedford, Mass.; D. N. TOWER, Superintendent, Cohasset, Mass.
Finance Committee. — A. R. HATHAWAY, Water Registrar, Springfield, Mass.; A. W. F. BROWN, Water Registrar, Fitchburg, Mass.; WM. MCNALLY, Water Registrar, Marlboro, Mass.

On motion of Mr. Thomas of Lowell, the Secretary was directed to cast the ballot of the Association, for the above named nominees, and they were declared elected.

Vice-President Walker then addressed the newly elected President as follows: —

"Before you take this chair I wish to say that I am glad to give it up to you, for I could not give it up to a better man. I shall go away with a good impression of you and of the Water Commissioners and all the gentlemen of Lynn — the ladies I am not acquainted with. [*Laughter.*] I know they are all pretty good looking, but I have not been introduced. I know that I express the opinion of all our members when I say we fully appreciate what you have done for us here, and that we cordially and gladly recognize you as our new President."

Mr. Haskell replied as follows: —

"Members of the New England Water Works Association, I thank you for this unexpected honor which you have conferred upon me. During the ensuing year I shall endeavor, as far as possible, to assist you in your efforts to make our meetings as interesting and instructive as they have been."

PLACE FOR HOLDING NEXT CONVENTION.

Mr. THOMAS. The Water Board of Lowell has authorized me to extend an invitation to the Association to hold their next annual convention in Lowell. The Association met there in 1884, in the early days of its history, and the Water Board would be glad to have you come again. I think many of our members would be interested in the Lowell Water Works, inasmuch as we get all our

water now from underground by a system of tube wells, or three different systems. We believe we have got a capacity of, at least, 8,000,000 gallons, and during the greater part of the year we are confident we can supply 12,000,000 gallons a day. It is something quite rare for a New England city to get such a large amount from wells, and something which we did not expect in Lowell when we first started in. I think it would be of interest to our members to inspect our system.

Mr. WALKER. I never liked Lowell because they beat Manchester in baseball, but I know if we go there we will be entertained in good shape, and I am heartily in favor of accepting the invitation.

Mr. COGGESHALL. I think this is a matter which had better be referred to the Executive Committee, and I will move that it be referred to them with full powers to report at some later meeting.

Mr. STACEY. Invitations to the Association have been rather rare for the last few years. And this now comes as a surprise to me, and a very agreeable surprise, as I have no doubt it will be to every member of the Association. But the motion that has been made is something which I had in mind to make, and for this reason: I think an invitation of this kind, coming from the city of Lowell, or any other of our thriving cities of New England, ought to be considered by a larger gathering of the Association than is present to-day at this meeting. I was about to make the motion, if it had n't already been made, to refer it to a committee, or to lay it on the table until we have a larger gathering so that we could accept the invitation with something of the enthusiasm and unanimity which it deserves. I heartily second the motion to refer to the Executive Committee, knowing that they will handle it properly, and will bring it before one of our large meetings in the winter.

Mr. Coggeshall's motion was adopted.

On motion of Mr. Stacey the Convention adjourned.

LIST OF EXHIBITS

IN CHARGE OF MR. HENRY F. JENKS, PAWTUCKET, R. I.

R. D. Wood & Co., Philadelphia, Pa., "Reduced" and "Cutting-In," special cast-iron water pipe connections.

Walworth Manufacturing Company, Boston, Mass., Hall tapping machine, pipe cutters, etc.

F. J. Dibble, Peabody, Mass., indicating and recording gauges for height and pressure of water.

Crosby Steam Gauge and Valve Company, Boston, steam gauges, pop safety valves, water relief valves, and water pressure recording gauge.

H. Mueller Manufacturing Company, Decatur, Ill., tapping machine and water works brass specialties.

Michigan Brass and Iron Works, Detroit, Mich., valves and hydrants and water works supplies.

A. P. Smith Manufacturing Company, Newark, N. J., pipe tapping machine.

Neptune Meter Company, New York City, water meters.

Pittsburg Meter Company, East Pittsburg, Pa., water meters.

H. R. Worthington, New York City, photographs of pumping machinery and water meter.

Union Water Meter Company, Worcester, Mass., water meters of various types, with brass and rubber pistons. Souvenir Cox's Kutter's pipe computer.

B. C. Smith, New York City, pipe cutting machine.

Hydraulic Construction Company, New York City, photographs and samples of well points and apparatus for subterranean water supply.

Ross Valve Company, Troy, New York, reducing and regulating valves.

The Ashton Valve Company, Boston, steam gauges and hydraulic relief valves for all purposes; boiler pop safety valves.

Dean Steam Pump Company, Holyoke, Mass.

Hersey Manufacturing Company, Boston, Mass., models of water meters.

Thomson Meter Company, Brooklyn, N. Y., water meters.

Taunton Locomotive Manufacturing Company, Taunton, Mass., copper gaskets.

National Meter Company, New York City, water meters.

Garlock Waterproof Packing Company, Boston, Mass., packing.

Rensselaer Manufacturing Company, Troy, N. Y., fire hydrants and valves.

Lead-Lined Iron Pipe Company, Wakefield, Mass., lead-lined iron pipe and fittings.

ATTENDANCE AT THE CONVENTION.

ACTIVE MEMBERS.

Everett L. Abbott, Brookline, Mass.; Frank A. Andrews, Nashua, N. H.; E. W. Bailey, Somerville, Mass.; Chas. H. Baldwin, Boston, Mass.; A. G. Bancroft, Reading, Mass.; L. M. Bancroft, Reading, Mass.; G. E. Batchelder, Worcester, Mass.; Oren B. Bates, Clinton, Mass.; Jos. E. Beals, Middleboro, Mass.; J. F. Bigelow, Marlboro, Mass.; W. R. Billings, Taunton, Mass.; Dexter Brackett, Boston, Mass.; A. W. F. Brown, Fitchburg, Mass.; J. T. Cavanagh, Quincy, Mass.; Geo. F. Chace, Taunton, Mass.; E. J. Chadbourne, Wakefield, Mass.; John C. Chase, Wilmington, N. C.; Robert L. Cochran, Nahant, Mass.; Wm. F. Codd, Nantucket, Mass.; Freeman C. Coffin, Boston, Mass.; R. C. P. Coggeshall, New Bedford, Mass.; Henry A. Cook, Salem, Mass.; F. H. Crandall, Burlington, Vt.; Geo. K. Crandall, New London, Conn.; J. W. Crawford, Lowell, Mass.;

G. E. Crowell, Brattleboro, Vt.; J. M. Davis, Rutland, Vt.; Francis W. Dean, Boston, Mass.; George E. Evans, Boston, Mass.; B. R. Felton, Boston, Mass.: Desmond FitzGerald, Brookline, Mass.; F. F. Forbes, Brookline, Mass.; Z. R. Forbes, Brookline, Mass.; Frank L. Fuller, Boston, Mass.; L. L. Gerry, Stoneham, Mass.; D. H. Gilderson, Bradford, Mass.; F. B. Gleason, Marlboro, Mass.; T. C. Gleason, Ware, Mass.; Albert S. Glover, Boston, Mass.; W. J. Goldthwait, Marblehead, Mass.; X. H. Goodnough, Boston, Mass.; Fred. W. Gow, Medford, Mass.; Amos A. Gould, Leicester, Mass.; E. A. W. Hammatt, Boston, Mass.; John C. Haskell, Lynn, Mass.; V. C. Hastings, Concord, N. H.; Louis E. Hawes, Boston, Mass.; S. S. Hatch, So. Norwalk, Conn.; F. W. Hodgdon, Arlington, Mass.; H. G. Holden, Nashua, N. H.; J. A. Huntington, Haverhill, Mass.; H. N. Hyde, Newtonville, Mass.; J. N. Jordan, Malden, Mass.; D. B. Kempton, New Bedford, Mass.; Willard Kent, Narragansett Pier, R. I.; P. Kieran, Fall River, Mass.; Frank C. Kimball, Boston, Mass.; Geo. A. Kimball, Boston, Mass.; Morris Knowles, Boston, Mass.; Jas. W. Locke, Brockton, Mass.; Jos. A. Lockwood, Yonkers, N. Y.; A. E. Martin, So. Framingham, Mass.; W. E. McClintock, Boston, Mass.; Wm. McNally, Marlboro, Mass.; Jas. W. Morse, Natick, Mass.; Chas. F. Murphy, Marlboro, Mass.; Thos. Naylor, Maynard, Mass.; Albert F. Noyes, Boston, Mass.; J. H. Perkin, Watertown, Mass.; Fred G. Perry, Pawtucket, R. I.; Thos. Roden, Arlington, Mass.; Geo. S. Rice, Boston, Mass.; W. H. Richards, New London, Conn.; Henry W. Rogers, Haverhill, Mass.; Daniel Russell, Everett, Mass.; A. H. Salisbury, Lawrence, Mass.; J. D. Shippee, Holliston, Mass.; Melville A. Sinclair, Bangor, Me.; John E. Smith, Andover, Mass.; Sidney Smith, Rutland, Vt.; Geo. A. Stacey, Marlboro, Mass.; Fred. P. Stearns, Boston, Mass.; John C. Sullivan, Holyoke, Mass.; D. A. Sutherland, Lynn, Mass.; Fred. L. Taylor, Brookline, Mass.; Lucian A. Taylor, Boston, Mass.; Jos. G. Tenney, Leominster, Mass.; Robert J. Thomas, Lowell, Mass.; Wm. H. Thomas, Hingham, Mass.; John Thomson, New York City; D. N. Tower, Cohasset, Mass.; D. W. Tenney, Methuen, Mass.; Chas. K. Walker, Manchester, N. H.; E. L. Wallace, Franklin Falls, N. H.; J. Alfred Welch, Methuen, Mass.; Geo. C. Whipple, Brighton, Mass.; John C. Whitney, West Newton, Mass.; Geo. E. Wilde, Menominee, Mich.; Geo. E. Winslow, Waltham, Mass.; E. T. Wiswall, West Newton, Mass.; Timothy Woodruff, Bridgeton, N. J.; W. G. Zick, New York City. Total, 102.

HONORARY MEMBERS.

"Engineering News," by Geo. C. Martin; "Engineering Record," by C. J. Underwood; "Fire and Water," by F. W. Sheppard. Total, 3.

ASSOCIATE MEMBERS.

Allis Company, The Edward P., by Jno. H. Lewis.
Ashton Valve Company, H. O. Hinkson, C. W. Houghton.
Blake Manufacturing Co., The Geo. F., by W. D. Fiske.
Crosby Steam Gage and Valve Company, S. G. Reed.

Dean Steam Pump Company, Chas. P. Dean, A. M. Pierce, F. H. Hayes, J. E. Batchelder.
General Manufacturing Company, by J. B. Cleaver.
Garlock Packing Company, by Jno. D. Lane and Jno. B. Perkins.
Hersey Manufacturing Company, by A. A. Blossom and Samuel Harrison.
Hydraulic Construction Company, The, by Wm. D. H. Washington and B. W. Mitchell.
Michigan Brass and Iron Works, H. H. Kinsey.
Morison, Samuel L.
Mueller Manufacturing Company, H., W. N. Dill.
National Meter Co., J. G. Lufkin.
Norwood Engineering Company, by W. A. Stevenson and H. T. Quint.
Pittsburg Meter Company, by A. G. Holmes.
Rensselaer Manufacturing Company, Fred A. Bates.
Ross Valve Company, by Wm. Ross.
Smith, Anthony P., by W. H. Van Winkle.
Smith, Benjamin C., by Fred A. Smith.
Snow Steam Pump Co., The, J. F. Holloway.
Standard Thermometer Company, F. J. Dibble.
The Sumner & Goodwin Company, by F. J. Sumner.
Thomson Meter Company, E. T. Ivins, S. D. Higley.
Union Meter Company, by J. B. K. Otis, Geo. H. Carr.
Walworth Manufacturing Company, by J. H. Eustis.
Wood & Co., R. D., by Jesse Garrett.
Woodman Company, The George, by H. A. Gorham.
Worthington, H. R., by Geo. B. Ferguson and J. M. Betton.

GUESTS.

Mrs. E. L. Abbott, Brookline, Mass.; Mrs. Chas. H. Baldwin, Boston, Mass.; T. Howard Barnes, Medford, Mass.; Jas. S. Beless, Salt Lake City, Utah; Mrs. Jas. S. Beless, Salt Lake City, Utah; Mrs. A. A. Blossom, Salem, Mass.; Miss Bessie E. Blossom, Salem, Mass.; Mrs. L. M. Bancroft, Reading, Mass.; Jas. S. Beal, Cohasset, Mass.; Mrs. J. E. Beals, Middleboro, Mass.; C. O. Beede, Lynn, Mass.; Mrs. A. H. Coulson, Salem, Mass.; Mrs. E. J. Chadbourne, Wakefield, Mass.; Miss Maud Cole, Andover, Mass.; Mrs. W. F. Codd, Nantucket, Mass.; Mrs. Geo. K. Crandall, New London, Conn.; D. F. Callahan, Marlboro, Mass.; Wm. H. Doty, Yonkers, N. Y.; Thos. E. Dwyer, Wakefield, Mass.; Mrs. Geo. E. Evans, Boston, Mass.; Mrs. F. F. Forbes, Brookline, Mass.; August Fells, Lowell, Mass.; Mrs. L. F. Fuller, Wellesley, Mass.; Mrs. Laura W. Forbes, Brookline, Mass.; J. F. Gleason, Quincy, Mass.; Chas. R. Gow, Boston, Mass.; Miss J. M. Ham, Boston, Mass.; Geo. R. Hall, Marlboro, Mass.; Mrs. Sam'l Harrison, Boston, Mass.; Edward F. Hughes, Boston, Mass.; Mrs. F. H. Hayes, Boston, Mass.; Mrs. H. G. Holden, Nashua, N. H.; W. T. Johnson, Boston, Mass.; S. H. Jones, Lowell, Mass.; Mrs. David B. Kempton, New Bedford, Mass.; Mrs. Willard Kent, Narragansett Pier, R. I.; Wm. B. Littlefield, Lynn, Mass.; Mrs. A. D. Lufkin,

Gloucester, Mass.; Wm. E. Mayberry, Braintree, Mass.; Mrs. J. Merrick, Boston, Mass.; Miss Edna Moffat, Richmond, Va.; Miss Helen Noyes, Newton, Mass.; Thos. P. Nichols, Lynn, Mass.; W. B. Nye, Boston, Mass.; Patrick O'Connor, Brookline, Mass.; H. R. Parker, Lynn, Mass.; Geo. E. Putnam, Lowell, Mass.; H. S. Proctor, Lowell, Mass.; Mrs. C. T. Proctor, Lowell, Mass.; Arthur W. Rayner, Newton, Mass.; Miss Vernie Robinson, Salem, Mass.; Mrs. Daniel Russell, Everett, Mass.; T. H. Rogers, Nashua, N. H.; Mrs. T. H. Rogers, Nashua, N. H.; Edwin W. Snow, Salem, Mass.; Mrs. E. W. Snow, Salem, Mass.; Mrs. Wm. H. Thomas, Hingham, Mass.; Miss Emma Thornton, Auburn, N. Y.; Mrs. M. A. Wallace, Franklin, N. H.; Mrs. Geo. C. Whipple, Newton, Mass.; E. A. Wood, West Newton, Mass.; Mrs. J. A. Welch, Methuen, Mass.; Mrs. Edgar Wordlyston, Salem, Mass.; Mrs. Geo. E. Winslow, Waltham, Mass.; Miss A. E. Winslow, Waltham, Mass. Total, 65.

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